FOOD TECHNOLOGY

PUBLISHED BY THE INSTITUTE OF FOOD TECHNOLOGISTS

Volume 5, Number 7
July, 1951

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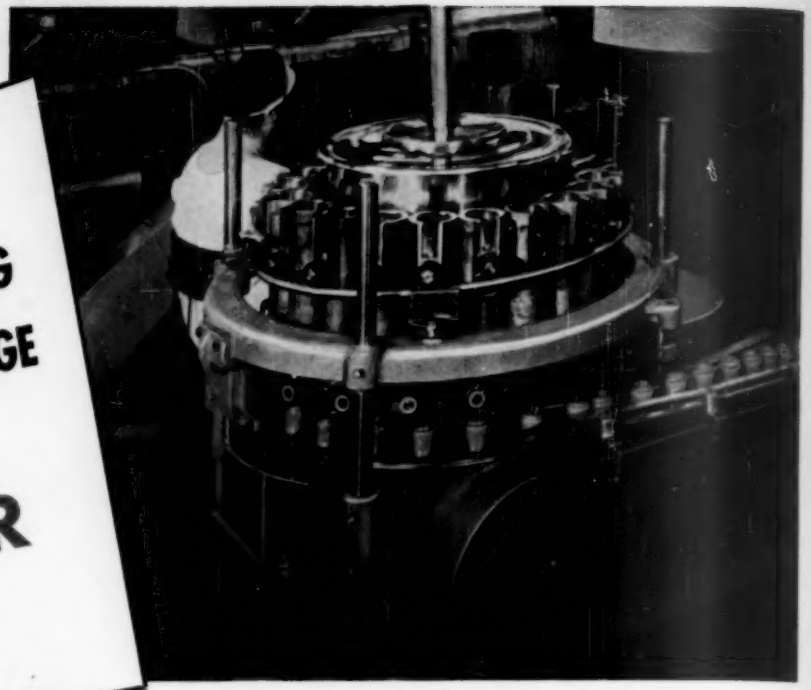

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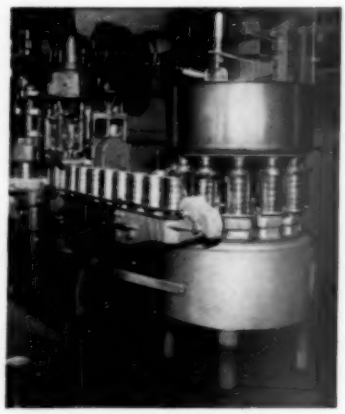

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An Objective Method for Measuring the Effect of Freezing Rate on Asparagus[a]

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(Manuscript received December 14, 1950)

Measurements of the force necessary to crush cooked segments of asparagus indicated texture differences between asparagus frozen very fast or very slowly. However, no significant differences could be found between the two sets of samples representing commercial quick freezing (in 3 hours) and home freezing (in 12.75 hours). Measurements on cooked snap beans which had been frozen slow or fast indicated no significant differences in the force required to crush.

In recent articles *(6, 7, 8)*, evidence was presented to show that rate of freezing has little effect on appearance, palatability, and vitamin content of many vegetables and fruits. Asparagus, however, seemed to be an exception, in so far as texture is concerned. This difference was found to be serious only when the speed of freezing was extremely slow. The adverse effect on texture was noted when 45 hours or more were required for the center temperature to fall from that of the room to —17.8° C. (0° F.). Other authors noted texture differences in the case of asparagus *(2, 4, 5)*.

Previous work with asparagus showed, in a qualitative way, that the thawed vegetable which had been frozen slowly was more easily crushed by gentle squeezing than that which had been more rapidly frozen. In the course of work on tomatoes, one of the authors (G.J.) made use of a device which measured the resistance of tomato skins to puncture *(3)*. It occurred to us that a modification of this equipment might be of some use in measuring the differences observed in asparagus. By replacing the plunger used for the tomato tissue by a flat metallic plate, a measure of the force necessary to crush the asparagus could be obtained with this apparatus. This metallic plate, 10 mm. x 25 mm. x 2 mm., soldered to a steel shaft (a needle) was held rigidly in place. Figure 1 shows the equipment used. Different types of crushing equipment were described by others *(1, 9)*.

METHODS

Asparagus spears, Martha Washington variety, medium size, cut to the five inch length, were blanched for 3.5 minutes in flowing steam, cooled, and prepared as follows. For each freezing condition, except that of freezing by immersion of the blanched spears individually in sirup, the spears were packed in 13 ounce cartons lined with cellophane. The spears were placed tip to butt to insure even packing. As described in a previous publication *(7)*, for each group a test carton was fitted with a thermocouple placed in the center of the package and another just inside the outer edge so as to follow the changes in temperature. One group was immersed in liquid nitrous oxide. In the second freezing method, a set of packages was frozen in an air blast (65 f.p.m.) at —45.6° C. (—50° F.). A third set of cartons was placed in a home freezing cabinet at —17.8° C. (0° F.) in still air. The fourth set of cartons was placed in a freezing cabinet at —11.1° C. (12° F.) in still air . The fifth set of cartons was packed in a small master carton of corrugated cardboard, lined with Cellulite one inch in thickness. This packed master carton was placed in the home freezer at —17.8° C. (0° F.) in still air. The last lot was comprised of spears which were individually frozen in 66% invert sugar sirup at —17.8° C. (0° F.). After freezing they were drained, dried, and packed.

The modified compression equipment (Figure 1), was used as follows: The frozen spears were prepared by plunging them into boiling water, and cooking them for six minutes, counting the time after the water returned to boiling. After this, they were drained and cooled. The cooled spears were cut into sections with a new razor blade after discarding the first half inch at the tip of the vegetable and one half to one inch from the butt. A section one inch long was cut from the center of the remaining portion for use in the test. The plate was placed lengthwise across the section of asparagus spear as is shown in Figure 1. The 25 mm. side of the plate is shown in this figure. The beaker on the right and the segment of asparagus on the left were brought into balance, with the plate just touching the asparagus segment. Water was then added from a 500 ml. dispensing burette with the stop cock opened full, until the indicator pointed to the pre-determined mark on the scale, which resulted in the deforming of the segment to the extent of 6 mm.

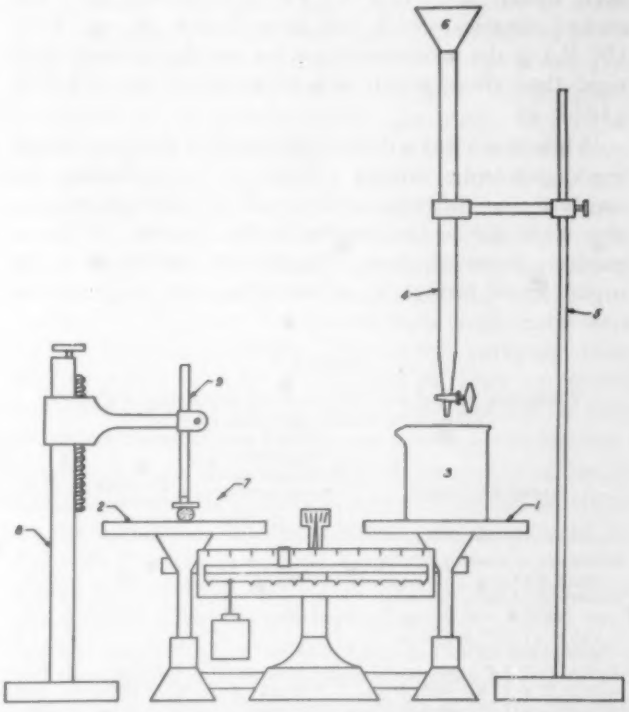

FIG. 1. Equipment used for determining the compressibility of asparagus. 1 and 2, platform; 3, beaker; 4, dispensing burette; 5, stand; 6, funnel; 7, asparagus segment; 8, rack and pinion; and 9, needle and plate holder.

[a]Approved by the Director of the New York State Agricultural Experiment Station for publication as Journal Paper No. 846. Presented at the Eleventh Annual Meeting of the IFT, New York, N. Y., June 20, 1951.

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However, tiny or jumbo asparagus would require different compressions. For comparable results, the same amount of compression must be used each time. It was found necessary to take the reading immediately, because it continued to change if left alone without the further addition of water. In practice this scale was more easily read by attaching a cardboard extension to it, and extending the lines to the upper edge of the cardboard. A needle was fastened on to the pointer so as to read more accurately the extended lines on the scale. The determinations were made at room temperature, 21.1° C. (70° F.).

RESULTS

Table 1 shows the readings obtained as a result of the experiments with cooked asparagus spears, cut as described before. This work was done on cooked spears which were originally frozen at different speeds. Each result is the average of 18 determinations. A relatively large number of readings was found to be necessary to secure a satisfactory average because of the variation among the different spears of asparagus in each lot. Statistical analysis of the figures showed that the least difference required for significance at the 1% level is 58. This means that the compression figures show that asparagus frozen by immersion of an entire carton in liquid nitrous oxide retained a higher degree of rigidity after cooking than those spears frozen by immersion in sirup at —17.8° C. (0° F.). Likewise, the spears frozen by immersion in sirup retained a higher degree of rigidity after cooking than those frozen in the air blast at —45.6° C. (—50° F.) The rigidity of those spears frozen in the air blast at —45.6° C. (—50° F.) were not significantly better after cooking than those frozen in the home freezer at —17.8° C. (0° F.) in still air. The cooked samples of asparagus which had been frozen in still air at —11.1° C. (12° F.) showed significantly less rigidity than those cooked samples which had been frozen at —17.8° C. (0° F.) in still air. The cooked samples which had been frozen at —17.8° C. (0° F.) in the insulated box were not significantly more rigid than those which had been frozen at —11.1° C. (12° F.).

While there was a downward trend in the corresponding organoleptic ratings (Table 1), it is obvious that some of the differences detected by the compression test were not so noticeable to the tasters. It is important, however, that a significant difference in the organoleptic ratings is shown when one contrasts the results on the cooked samples frozen by immersion with those frozen in the insulated box.

It should be noted, however, that while the organoleptic results failed to show differences between freezing at —17.8° C. (0° F.) in still air, and freezing at —11.1° C. (12° F.) in still air, some of the tasters were of the opinion that the samples frozen at —11.1° C. (12° F.) were inferior.

The crushing tests placed the cooked asparagus spears frozen at different rates in three different groups: first, the immersion group, second, that frozen at —45.6° C. (—50° F.) in the air blast and that frozen in still air at —17.8° C. (0° F.), and third, the samples very slowly frozen. Differences within each of these groups are apparent. These differences were significant, however, only in the immersion group.

To further check this equipment, tests were made on snap beans, a vegetable which shows no differences, organoleptically, when samples are frozen at different speeds. Snap beans, frozen at —40° C. (—40° F.) with the air blast (650 f.p.m.), —17.8° C. (0° F.) in still air, and —17.8° C. (0° F.) in the insulated box, were immersed in rapidly boiling water, cooked for 10 minutes after the water returned to boiling, drained, and cooled. The beans, normally segmented for packaging, were used in the crushing equipment without further cutting. The average figures obtained for cooled beans which were originally frozen as just given, were: 276, 283, and 301. Statistical analysis of the figures showed no significant differences between them. The corresponding organoleptic tests showed the following figures: 7.4 for those frozen originally in the air blast, 7.7 for those frozen at —17.8° C. (0° F.) in still air, and 7.6 for those frozen at —17.8° C. (0° F.) in the box insulated with one inch of Cellulite.

These organoleptic results showed no differences in texture in the beans after cooking regardless of the speed of freezing employed, which substantiates the compression figures. Also, this checks the conclusions concerning the effects of speed of freezing on snap beans reported by Lee, Gortner, and Whitcombe *(7)*.

TABLE 1

Pressures needed to crush cooked [c] asparagus segments previously frozen at different rates

Freezing treatment	Time from room temperature to center temperature of —17.8° C. (0° F.)	Crushing pressure	Organoleptic rating [d]
		g.	
Immersion of whole carton in liquid N_2O	22 min.	561	7.6
Immersion of spears in sirup at —17.8° C. (0° F.)	30 min. (Approx.)	477	7.6
—45.6° C. (—50° F.) in air blast of 650 f.p.m.	3 hours	289	7.2
—17.8° C. (0° F.) still air	12.75 hours	267	6.6
—11.1° C. (12° F.) still air	24 hours	189	6.6
—17.8° C. (0° F.) insulated [e]	62.5 hours	174	5.9

[c] Samples were cooked for 6 minutes after the water returned to boiling.

[d] Based on choices of 1, lowest quality, to 10, highest quality.

[e] Box insulated with 1 inch thickness of Cellulite.

SUMMARY

An objective test is presented which seems to measure with reasonable accuracy the effects of freezing rate on the texture of cooked asparagus by means of a crushing action. The results indicate that although extremely fast or slow freezing will influence the firmness of asparagus spears, cooked asparagus spears which had been frozen in 3 hours are substantially equal in resistance to crushing to those cooked spears which had been frozen in a home freezing cabinet. This test also was applied to cooked snap beans which had been previously frozen under conditions of varying speeds of freezing. The differences in texture as measured by the crushing of several such samples were not significant.

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Objective Testing of Vegetable Quality[a,b]

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(Manuscript received May 3, 1951)

Substantial advances are being made in the development of precise methods and instruments for measuring quality factors of vegetables. Methods of measurement of appearance factors of quality such as color; of kinesthetic factors such as tenderness, fibrousness, and succulence; and of flavor factors such as acidity, sweetness, salt, and specific off-flavors are discussed. The objective methods are illustrated with examples on specific vegetables.

Objective quality measurements of frozen foods have for their goal the establishment of precise and accurate specifications to characterize the quality factors of any given lot of material. Such specifications are of benefit to the grower of the raw material, the processor, the broker, the distributor, the retailer, and the consumer. This entire problem of quality measurement of horticultural products has been the object of considerable study for some years in the Horticulture Department of the University of Maryland.

The engineer, concerned with the manufacture of a machine constructed of inert material, using precision tools and measuring devices, frequently complains of the difficulties involved in setting up specifications for his product. His difficulties are minor compared to those of the food technologist who deals with inherently variable biological material, and whose ultimate measuring device is human evaluation. Thus it is logical to make the following assumptions: First, because of their natural variability, food specifications cannot be very narrow and rigid; and second, the suitability of any objective, i.e., physical or chemical method must be evaluated by its agreement with human evaluation as measured by expert or consumer panels.

Two principles are involved in any type of measurement; namely, precision and accuracy, where precision is the ability to duplicate results, with one instrument or with different individual units of the same instrument, while accuracy refers to the degree to which the instrument or procedure reflects human evaluation. Precision may be measured statistically by the coefficient of variability. Thus for example, Walls, Kemp, and Stier *(24)* found that the coefficient of variability for tenderometer readings on raw peas was 1.56%, and for texturemeter readings, 7.5%. Accuracy may be measured statistically by the coefficient of correlation, where objective values are correlated with human evaluation in the form of a testing panel of judges. A correlation coefficient of 1.0 indicates perfect accuracy. In general, 0.8 is considered acceptable, although 0.9 is much more desirable *(2)*. Ordinarily greater precision tends towards greater accuracy, although that is not always true. For example, the coefficients of variability for the alkali digestion and blendor methods of determining fiber in green beans were found to be 4.2 and 8.0 respectively; however, the correlation coefficients were 0.75 and 0.82 respectively. Thus in this particular case, the less precise blendor method was in closer agreement with human evaluation although it was less precise than the alkali digestion method.

It is obvious that the main advantage in objective methods lies in the potential improvement in precision or duplicability. In other words, an instrument or chemical procedure is more likely to provide identical results for identical samples of food, under conditions which might affect the precision of a human judge, such as lapse of time, differences among individual judges, and the state of health and discriminatory ability of the judge, etc. Less advantage may be expected for the objective method in terms of improved accuracy, since the accuracy of the objective method as such is measured in terms of agreement with human evaluation, except

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[a] Presented before the Eleventh Annual Meeting of the IFT, New York, N. Y., June 20, 1951.

[b] Paper No. 110, Contribution No. 2292 of the Maryland Agricultural Experiment Station. Partial Support from Regional Research and Marketing Act Funds (Project NEM$_3$).

in the sense that the evaluation of one particular judge may not necessarily be in close agreement with human evaluation as a whole. Thus in one instance where 10 judges scored samples of tomato juice for color, the correlation coefficients between each judge's score and the average score ranged from 0.57 to 0.91, while the correlation coefficient between the average score and the best objective method was 0.94. One additional advantage is inherent in the objective method, which is the automatic elimination of the human element, thus providing unbiased values, whereas human evaluation is always, whether consciously or not, subject to bias.

The overall quality of foods may be defined as the sum total of characteristics of the given food item which influences the acceptability or the preference for that food, by the consumer. These quality characteristics, or factors, are distinct and are not necessarily all positively related to each other. For example the maturity of green beans may be negatively related to their flavor *(5)*. Hence, it is necessary to use some system such as is employed by the United States Department of Agriculture Inspection Service *(23)*, where each quality factor is carefully defined, and evaluated separately. The factors involved in the quality evaluation of frozen foods may be classified into three general categories, namely appearance factors, kinesthetic factors, and flavor factors. All of these are important, although in some instances only one factor may be dominant (Table 1).

TABLE 1

Classification of quality factors and objective methods for their determination

Appearance factors	Objective methods
Container and label	
Size	Screens, micrometers, sedimentations.
Shape	Displacement, dimension ratios.
Wholeness	Counts, dimension ratios.
Consistency	Consistometers, viscosimeters.
Defects	Photographs, drawings, models.
Gloss	Goniophotometer, gloss meter.
Color	Color dictionaries, cards, reflectance and transmittance meters.
Kinesthetic factors	
Chewiness	Shear-pressure, insoluble solids.
Fibrousness	Shearing force, fiber content.
Succulence	Extractable juice, moisture content.
Grittiness	Grit content.
Flavor factors	
Sweetness	Hydrometers, refractometers, sugar content.
Saltiness	Sodium or chloride content.
Sourness	pH, total acids.
Off flavors	
Enzymatic	Enzyme activity.
Breakdown	Free amino acids, volatile reducing substances.
Characteristic odor and flavor	

Appearance Factors. Factors of quality included in this group are those which the consumer evaluates with the eye; hence, they are the first to confront the consumer. It is usually on the basis of the impression gained from the appearance of the product alone that it is accepted or rejected. Since this decision is made before the consumer has the opportunity of preparing the food for consumption, these appearance factors are therefore undoubtedly most important in the case of the first purchase, whereas other factors may be more important for repeat purchases. In the case of packaged foods, the container and especially the label are extremely important in their contribution to the appearance of the product.

Other factors that may be included in the appearance category are such items as size, shape, pattern, and wholeness, most of which may be measured easily by relatively simple devices such as scales, screens, micrometers, planimeters, sedimentation tests, or displacement in liquid media.

Defects of various kinds also fall in this category. Although they are also usually rather easily determined, (as in the case of number of split skins in frozen peas, or unsnipped ends of green beans), they occasionally present more difficult problems, usually qualitative rather than quantitative. Thus it is difficult to determine, for example, whether a particular discolored spot is dark enough or large enough to be called a blemish, or whether two small light spots are only as unacceptable as one darker or larger spot. Attempting to establish limits for such minutely detailed factors may result in unwieldy and lengthy procedures and specifications.

Another approach is through the employment of photographs, models, and drawings such as those being used and developed by the standardization division of the Production and Marketing Administration as visual aids in grading for defects, blemishes, and "character" factors.

Gloss is an appearance characteristic that has been almost entirely overlooked in the objective evaluation of foods, although it is obvious that this factor which is usually termed finish in apples, and shine, or polish in other products is an evident and important factor of appearance in products such as raw apples, tomatoes, and strawberries. It is entirely possible that even one lot of peas may appear more desirable than another because of a difference in gloss. This factor is being measured in the paint industry by the goniophotometer, and the gloss meter. Thus the instruments in their present or modified form are available which are capable of measuring the gloss factor. However, the work of applying these instruments to the measurement of the gloss factor in specific foods remains to be done.

The objective measurement of color in foods has received considerable attention. Reference is frequently made to color dictionaries which usually are not entirely satisfactory because of the difficulty of matching color, and also because differences in color evident to the human eye are frequently smaller than the spacings found in color dictionaries. The Munsell system of color notations, has been used with greater success, especially when used with a disk colorimeter where the angle and intensity of the light source were controlled, and the lens rotated instead of the color discs which were left stationary so that the proportion of the different color discs could be changed while the instrument was in action, thus making it possible to match colors in a relatively short time *(19)*. Such instruments were manufactured in limited numbers by Keuffel and Esser, and Bausch and Lomb. Unfortunately both firms decided that these instruments were not profitable to manufacture, so that no satisfactory disc colorimeter is

now available. Furthermore, the disc method is not entirely objective, since the matching of the color is done by the eye.

With the development of photoelectric colorimeters and spectrophotometers, abridged spectrophotometric method of color measurement were suggested involving the extraction of the plant pigments and the measurement of their concentration at specific wave lengths. These methods are generally satisfactory to the extent that the color impression of a particular food is correlated with the concentration of the particular pigment that is extracted *(13)*. The obvious limitations of the abridged spectrophotometric methods are that the color as seen by the eye may not necessarily be closely related to the concentration of the extracted pigment, and that the internal coloration of the product might be unduly over-emphasized, since it is often the outer surface of the product that is responsible for the color impressions. More recently several photoelectric instruments have become available which are capable of measuring reflected light in terms of tri-stimulus colorimetery, so that results obtained with these instruments may be calculated in terms of a standard observer. Psychologically, these terms are value, or the lightness or darkness of the color; hue, or the dominant wave length, i.e., whether the color is yellow or orange, etc.; and chroma, or the intensity of the color *(8)*.

The most basic of these instruments, and by far the most expensive is the Hardy spectrophotometer, equipped with a tristimulus integrator. Another instrument which is much less expensive, and more practical but which is still unusually precise, is the Hunter color-difference meter. A third, and still less expensive instrument is the Photovolt reflectometer, which, however, is less automatic and not as precise *(9)*.

Since results with tri-stimulus color meters are obtained as three distinct values, they are frequently difficult to explain unless they are converted into single color values. This can be accomplished by the use of multiple regression equations, and for practical purposes, charts or nomographs may be employed, where the discreet tri-stimulus values may be located and the color value read directly without calculation. An example of such a chart is given in Figure 1, where the values for tomato juice are located on a chart, and the equivalent U. S. grade is obtained.

Besides providing a value for the color factor as such, a color or pigment determination may occasionally provide information on other quality characteristics, as for example greenness of peaches and apricots is closely associated with their ripeness *(15)* and percent whites in lima beans is associated with the stage of maturity *(23)*.

Kinesthetic Factors. Factors of quality included in this group are those which the consumer evaluates with his sense of feel. Since most processed products are not hand felt, these characteristics are largely determined by mouth feel and included such factors as tenderness or hardness, chewiness, juiciness, grittiness, and fibrousness. In general these factors lend themselves readily to objective measurement by the use of mechanical instruments. Thus a considerable array of tenderometers, texturemeters, punctiremeters, succulometers,

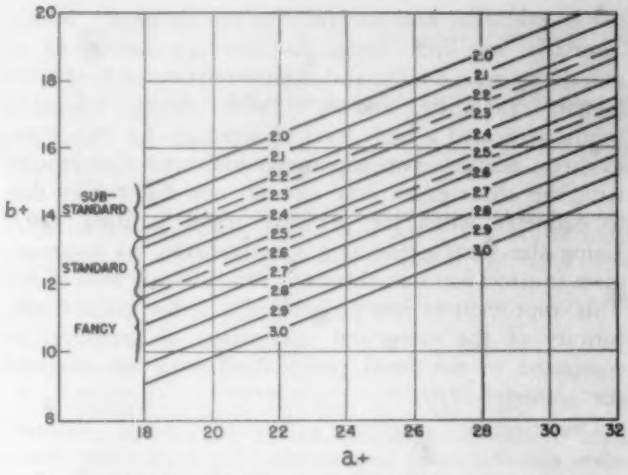

FIG. 1. Relation of *a* and *b* values obtained with the Hunter color and color difference meter, to official PMA grades for color of tomato juice.

fibrometers, and pressure testers are available. These instruments vary in their precision as well as in their accuracy. Considering the tremendous variability encountered in food materials because of differences in varieties, growing conditions, and soils, these instruments frequently require special calibration for use with different varieties, and perhaps in different geographical locations.

In spite of the large array of instruments that have been developed for the purpose of measuring these kinesthetic factors, actually there are only a few basic principles involved *(17)*. These are: 1, shearing force-pressure, which simulates the resistance offered by the food to the crushing action of the teeth; 2, shearing, or cutting force alone, which simulates the resistance of differentiated portions of the food such as fiber strands, to chewing; and 3, succulence, which simulates the amount of juice that is squeezed out of the food during mastication. All these measurements require the application of force; hence, it is logical to assume that all such kinesthetic measurements can be accomplished with one power unit in the same way that all color measurements may be made with one color instrument. Work is now under way at the University of Maryland on developing such a unit *(11)*. Three different test cell assemblies may be provided for use with the same power unit, to accomplish the three different types of testing. Thus, one test cell, similar in design to the pea tenderometer *(18)*, may be used to measure hardness or firmness of such different products as peas, lima beans, sliced apples, tomatoes, cherries, strawberries, or sweet potatoes. Of course, the range of values for lima beans will be many times higher than for strawberries; however, both may be tested with the same instrument and test cell, but with the use of gauges of different ranges. Another test cell similar in design to the asparagus fibrometer *(26)*, may be used for measuring the fibrousness of such commodities as asparagus, green beans, and celery, while a third test cell, similar in design to the succulometer *(16)*, may be used to test the succulence of sweet corn, apples, or potatoes.

Extensive studies during the 1950 season on peas, indicated that shear-press values are practically identi-

cal in precision and accuracy to tenderometer values. Similarly for lima beans, the average coefficient of variability was 2.41%, and the correlation of 0.93 with human evaluation, and 0.98 with alcohol insoluble solids, indicated a high level of accuracy for this commodity. Studies with asparagus indicated that results with the shear-press may smooth out differences due to diameter when the pressure tester is used *(10)*. Using the shear-press as a succulometer, an improvement in precision was obtained from 1.04 ml. to 0.75 ml. This improvement was probably due to the greater uniformity of the motorized application of pressure, as compared to the hand pump used with the original succulometer *(16)*.

Quantitative, empirical, physico-chemical methods may also be used successfully for measuring these kinesthetic factors, but the empirical procedure must be adhered to rigidly if precise results are desired. Examples of such procedures are the alcohol insoluble solids test for peas and corn *(1)*, the fiber test for green beans *(4)* and asparagus *(10)*, the stone cell test for pears *(14)*, and the pericarp test for sweet corn *(16)*.

Flavor Factors. Factors of quality included in this group are those which the consumer evaluates with his sense of taste and smell. In contrast to appearance and kinesthetic factors, these flavor factors are difficult to evaluate objectively. In fact, it has been suggested that since flavor is a physiological sensation, it is by definition subjective, and therefore, not subject to objective measurement *(22)*. The degree of sweetness can be approximated by a sugar determination, or where possible more rapidly but still less accurately by a refractometer or hydrometer. Saltiness may be approximated by a determination of chloride or sodium content. Sourness may be measured by total acid determination, or by the use of a pH meter.

Some progress has been made on the detection of off flavors. Here the component that is determined is not usually responsible for the off flavor or odor, but merely associated with it. Thus, various enzyme activity determinations were suggested as indicators of off flavor resulting from under-blanching of frozen vegetables *(7)*. Oxidation-reduction potential *(25)* and free amino acids, have been suggested as indicators of off flavor in stored fruit and fish *(21)*.

Rapid, practical methods for determining the essential flavoring constituents of foods have not been developed as yet. Whatever work was initiated was abandoned with no practical results. Some aids however, are available that reduce the hazard of purely subjective evaluation of flavors. The Henderson-Crocker system of odor notation is helpful in this direction *(3)*. Much progress has been made in improving the design, precision, and interpretation of taste testing panels, so that these essentially subjective methods are somewhat more objective in that they are more precise and comparable *(6)*.

Maturity and Ripeness. With certain foods there may be a group of quality characteristics that are rather constantly associated, so that one measurement may be a satisfactory index of the status of all the associated factors. Maturity and ripeness are such concepts. Although these terms have been used in various ways, they may be defined here, as the stage of development of the organism or that part of the organism that is used as food. The two terms are defined in the same way, except that maturity is used for vegetables such as peas, beans, and corn, where an immature stage is desirable, while ripeness is used for fruits, such as peaches, apricots, or tomatoes, where a fully ripe condition is desirable. Thus, for example when the tenderometer is used to determine the maturity of a given variety of peas, some indication is provided not only of the hardness of the peas, but also their size, color, sweetness, likelihood of bruising, gain or loss in size during blanching, and nutritive value. Similarly, if a spectrophotometric determination of the presence of green pigment is made for peaches, information is gained not only of the quantity of the underlying green color, but also of the firmness of the flesh, the sugar-acid ratio, and the ease of handling in the plant, the concentration of the syrup required, and the probable fill in weight *(15)*.

Weighting the Quality Factors

After the separate quality factors are established, and measured adequately, they must be recombined into one single grade in order to determine the overall quality of the product. Before this recombination occurs, it is first necessary to assign a relative weight to each factor of quality. This has been done by a number of different methods, as for example the relatively simple method used by the U. S. Department of Agriculture *(23)*, or the more complex method suggested by Plank *(20)*. However, the weighting in all these procedures is arrived at subjectively. Statistical methods are available where the relative weights to be assigned to different quality factors may be arrived at objectively. This can be done through the use of multiple correlation calculations where the individual factors or tests of quality may be correlated simultaneously with an overall grade. By utilizing such a procedure for green beans, it was found that maturity as measured by percent seed accounted for 29% of the total; fiber, as measured by the blendor fiber method, 27%; color, as measured the concentration of the green pigment, 15%; and flavor, as measured by a taste testing panel, 29%.

CONCLUSIONS

Much progress has been made in the objective evaluation of appearance and kinesthetic factors of quality. Although some flavor attributes and some specific off flavors may be measured objectively, the determination of flavor as such is still largely in the hands of the taste testing panel. This panel itself is improving in precision, so that it is no longer advisable to depend entirely on the experience or whim of the sales manager or broker in establishing quality specifications.

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The Nutritive Value of Canned Foods[a]
The Effect of Storage on the Ascorbic Acid Content of Canned Tomato Juice and Tomato Paste

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(Manuscript received March 23, 1951)

Tomato juice and tomato paste made from the same lots of tomatoes were prepared at commercial canneries. Samples were stored at 10° C. (50° F.), 21° C. (70° F.), and 29.5° C. (85° F.) for 24 months, and at 38° C. (100° F.) for 12 months. The retention of ascorbic acid was determined after canning, and after various periods of storage. Tomato paste was found to lose ascorbic acid at a more rapid rate than tomato juice at all temperatures. High retention was obtained for both products after storage at 10° C. (50° F.) for 24 months. The canning procedure, the initial level of ascorbic acid, and minor variations in copper content were found to have little effect on the rate of loss of ascorbic acid. Relatively minor amounts of dehydroascorbic acid and diketogulonic acid were found in samples stored at all temperatures for the maximum storage periods. Low temperature storage is recommended for obtaining maximum retention of ascorbic acid in tomato paste.

Studies conducted in connection with the National Canners Association-Can Manufacturers Institute nutrition program *(14)* have investigated the retention of ascorbic acid and other vitamins during the commercial canning of tomato juice *(5, 9)* and of ascorbic acid during the commercial canning of tomato paste *(8)*. The retention of ascorbic acid during the storage of tomato juice has also been the subject of extensive investigation *(6, 13)*. No comparable studies have been made of the retention of this vitamin during the storage of tomato paste.

Hummel and Okey *(7)* have recently reported the results of a study on the relation of concentration of canned tomato products to storage losses of ascorbic acid. The above investigators have reported results showing that concentrated tomato products lose ascorbic acid at a considerably greater rate than unconcentrated tomato products. The studies conducted by these investigators were performed on solid-pack tomatoes, tomato juice, and tomato paste, obtained from commercial canneries and put into storage at various times after packing. Comparable tomatoes were not used for the preparation of the three different products. An experimental pack of solid-pack tomatoes, juice, and paste made from the same lot of tomatoes was prepared in the laboratory and stored in glass containers. Some of these samples were stored at room temperature, which varied

[a] This is the 43rd of a series of papers sponsored by the National Canners Association-Can Manufacturers Institute dealing with the general subject "Nutritive Value of Canned Foods."

from 20° to 25° C. (68° to 77 F°.) and some at 37° C. (99° F.).

The studies reported herein differ from those of Hummel and Okey in that tomato juice and tomato paste were prepared at three commercial tomato products canneries, from the same lots of tomatoes, canned in the same sizes of cans, and immediately placed in storage at four controlled temperatures ranging from 10° C. (50° F.) to 38° C. (100° F.). For comparison, a commercial pack of tomato juice, packed at a fourth cannery, was stored at the same temperatures. Ascorbic acid was determined before canning, at the time the samples were placed in storage, and at periodic intervals up to a total period of 24 months, except for the samples stored at 38° C. (100° F.) which were stored for 12 months. In these studies three different methods of paste manufacture were employed. A lot of tomato juice fortified with ascorbic acid was also included in the experiment.

PREPARATION OF SAMPLES

Comparable packs of tomato juice and tomato paste were prepared during the 1948 season at three commercial canneries. These samples were packed in 6-ounce (202 x 308) cans at two of the canneries, and in 8-ounce (211 x 304) cans at the third cannery. These are the can sizes customarily used for packing tomato paste for retail distribution. Although tomato juice is not ordinarily packed in these container sizes, the 6 and 8-ounce cans were used in order to eliminate can size as a variable in this experiment. Tomato juice was not being packed commercially at any of the three tomato paste canneries; hence juice was taken from the paste line at the stage immediately prior to concentration and canned. In order to compare the behavior on storage of the experimentally canned juice with that of commercially prepared juice, samples of tomato juice packed in No. 2 (307 x 409) cans were obtained from the canning line at a fourth cannery which was packing only tomato juice. All of the containers used in this experiment were plain cans containing no enamel coatings. Since the difference in concentration of ascorbic acid between that in tomato juice and that in tomato paste was thought to be a possible factor influencing storage losses, one lot of juice was prepared at one of the three tomato paste canneries to which was added additional ascorbic acid to bring it approximately to the level of tomato paste.

The following is a description of the canning operations and experimental procedure employed, at the three tomato paste canneries (canneries A, B, and C), and the tomato juice cannery (cannery D). All of the tomatoes used in these studies were of the Pearson and Santa Clara Canner varieties.

Cannery A. The tomatoes were washed and steamed and sound fruit was removed for canning as whole tomatoes. The remainder of the tomatoes went through a chopper, followed immediately by a heat exchanger where the temperature was raised to 79.5-82° C. (175-180° F.) in less than one minute. The pulp then went through a cyclone and a finisher, at which time the skins, seeds, and coarse pulp were removed. The finished pulp was pumped to a holding tank and held at 76.5-82° C. (170-180° F.) approximately 30 minutes, after which it was pumped to the vacuum concentrator.

Juice was taken from the holding tank in pails and filled by hand into 6-ounce cans at a filling temperature of 71-74° C. (160-165° F.). The cans were run twice through a continuous cooker, giving at each pass a cook of 13 minutes at 100° C. (212° F.). The total elapsed time from the beginning to end of the processing period was 30 minutes. The cans were water cooled for 6 minutes.

The juice for paste manufacture was concentrated in a batch using a Pfaudler vacuum pan operating under 26 inches of vacuum to a final concentration of about 27% total solids. After the vacuum was released, the paste was passed through a heat exchanger and heated to 88-93.5° C. (190-200° F.). It was then filled into 6-ounce cans and processed for 13 minutes at 100° C. (212° F.) followed by a 6-minute water cool, after which the temperature of the paste was 57-60° C. (135-140° F.). It was then allowed to air cool to room temperature.

Cannery B. The tomatoes were washed but not steamed. All of the tomatoes were chopped before heating, preheated to 54.5° C. (130° F.), and then passed through a cyclone followed by a finisher.

Juice was taken at this stage and filled into 8-ounce cans at a temperature of 51.5° C. (125° F.). The cans were exhausted for 5 minutes at 93.5° C. (200° F.) which raised the temperature of the juice to about 74° C. (165° F.) at the time of sealing. The cans were cooked for 30 minutes in a tank of boiling water, and water cooled.

For paste manufacture, the juice from the finisher passed through a heat exchanger which raised the temperature to 90.5-93.5° C. (195-200° F.). The juice was then heated in a stainless steel open tank fitted with copper coils until the concentration of the juice was raised from about 6% to 8%. It was then pumped to a vacuum concentrator operating at 76.5° C. (170° F.) under 17 inches of vacuum, in which the concentration of the juice was raised to about 11%. The remaining concentration was made at atmospheric pressure in a two-stage Peebles concentrator. The concentration was accomplished by allowing the juice to flow in a thin film down a cylinder having a shell temperature of about 143.5° C. (290° F.) against a counter current of air. The first stage raised the concentration of the product to about 16% and the second stage to 26%. The approximate total time in the two atmospheric pressure units was 2 minutes. This time was interrupted, however, by a holding tank with continuous in and out flow, located between the two units, in which the product remained for an undetermined period of time.

Since the concentration of juice was a continuous operation, the time required for a given lot of raw material to pass through the system could only be estimated. According to plant records, this time was estimated at 45 minutes; hence, the samples of paste were filled into 8-ounce cans approximately 45 minutes after juice was taken from the holding tank. The paste was filled at 82-85° C. (180-185° F.) and cooked for 15 minutes in boiling water, followed by water cooling.

Cannery C. Washed and trimmed tomatoes were crushed, heated quickly to 93.5° C. (200° F.) in a heat exchanger, and run through a pulper and a finisher. The juice was pumped to a holding tank where it was held for 20-30 minutes, during which time it was heated to 99° C. (210° F.) by means of copper heating coils and mixed by means of a stirrer.

Juice was removed from this tank and transferred to an automatic filler where it was filled into 6-ounce cans at a temperature of about 93.5° C. (200° F.). The cans were processed for 3 minutes at 100° C. (212° F.) in agitating cookers, and cooled to 32-38° C. (90-100° F.).

An additional 2 gallons of juice were taken at this cannery and 30.9 grams of ascorbic acid were dissolved and stirred into the juice. This batch of fortified juice was canned and processed in the same manner as the unfortified juice.

For paste manufacture the juice was pumped into a continuous Buflovak concentrator, in which it was concentrated under 26 inches of vacuum to a solids content of about 26%. At about 60 minutes after juice from the holding tank commenced to enter the concentrator, samples of paste were taken consecutively from the canning line. It was estimated that after about this interval of time essentially all of the paste would be derived from juice taken from the holding tank from which the juice samples were taken.

The paste was filled into cans at about 93.5° C. (200° F.), processed for 3 minutes at 100° C. (212° F.), and water cooled.

Cannery D. This cannery was manufacturing tomato juice only and a series of cans was taken directly from the canning line after processing. The tomatoes were steamed before crushing, heated to a high temperature in a heat exchanger and passed through a coarse and a fine finisher. The juice was pumped through Pyrex tubing to a deaerator whose main purpose was to prevent foaming at the filler by removing air from the line. It was then filled directly into cans without holding;

the cans were salted by means of a salt dispenser and vacuum closed. The cans were processed for 14 minutes at 109° C. (228° F.) in a continuous cooker and water cooled to 32-38° C. (90-100° F.). The entire operation was very rapid, the time between crushing the tomatoes and sealing the juice into cans being not more than 10-15 minutes.

At canneries A and B, 114 cans each of juice and of paste were packed, and at cannery C 186 cans each of paste and of unfortified juice, and 42 cans of fortified juice, were packed.

Ascorbic acid determinations were made at each of the canneries on samples of the raw juice immediately after it was taken from the canning line.

Analytical Methods

Ascorbic acid was determined by the indophenol dye titration method *(3)*, using 3% metaphosphoric acid as the extracting agent, on the samples of raw juice tested at the canneries. The Loeffler and Ponting method *(11)* was used on the samples tested after the various storage periods. In this method 10 g. of paste were diluted to 200 ml. with 1% metaphosphoric acid and 20 g. of juice were diluted to 100 ml. with 1% metaphosphoric acid. Ascorbic acid, dehydroascorbic acid, and diketogulonic acid were determined on a special series of samples by a modification of the method of Roe, Mills, Oesterling, and Damron *(16)*. Stannous chloride was not used in conjunction with the 5% metaphosphoric acid as specified in the above method since difficulty was experienced in removing excessive turbidity from the solutions after the hydrogen sulfide precipitation of tin, and since stannous chloride was found not to be necessary in preventing oxidation of the ascorbic acid. One percent thiourea in place of the stannous chloride was added to the solution in which diketogulonic and dehydroascorbic acids were determined.

Total solids was determined by means of a Zeiss sugar and oil refractometer on the filtrate from tomato juice and tomato paste *(15)*. The pH was measured by means of a glass electrode pH assembly. Copper was determined by the carbamate method (1), omitting the special procedure necessary for the separation of bismuth, cobalt, and nickel. Iron was determined by the o-phenanthroline method (2) after preliminary wet ashing of the samples, except that hydroxylamine was used in place of hydroquinone as reducing agent.

Storage and Testing of Samples

The samples were transported to the laboratory within 24 hours after packing and cans from each lot of unfortified juice and paste were placed in storage at 10°, 21°, and 29.5° C. (50°, 70°, and 85° F.), respectively. In addition to the above three temperatures, samples of juice and paste from cannery C and of the commercial juice from cannery D were also placed in storage at 38° C. (100° F.). The fortified juice from cannery C was stored only at 21° C. (70° F.).

The initial ascorbic acid determinations were made on the canned samples within 4 to 7 days after packing. The cans used for the initial testing were placed in the refrigerator as soon as they arrived at the laboratory and held there until they could be tested.

Samples stored at 38° C. (100° F.) were tested at 1, 4, 6, 8, 10, and 12 months of storage. Samples stored at 21° C. (70° F.) were tested, at 18 and 24 months of storage, in addition to the above except that the first testing of the 21° C. (70° F.) samples was made at the end of 2 months instead of one month. The samples stored at 10° C. (50° F.) were tested at 6, 12, 22, and 24 months of storage.

At each testing period from 4 to 6 cans of each lot of juice or paste stored at the same temperature were composited and ascorbic acid, total solids, and pH were determined.

At the conclusion of the testing period, the remaining samples were placed in the refrigerator at 7° C. (45° F.). Certain of these remaining samples were used for the determination of copper and iron, and of ascorbic acid, dehydroascorbic acid, and diketogulonic acid by the 2, 4 dinitrophenylhydrazine method previously described.

RESULTS

The ascorbic acid retentions found in the samples of tomato juice and tomato paste are shown in Figures 1, 2, 3, and 4 for canneries A, B, C, and D respectively. The data show conclusively that at each storage temperature tomato paste loses ascorbic acid at a more rapid rate than tomato juice. The results also show that temperature has a profound effect on the rate of this loss. At the higher temperatures both juice and paste lose ascorbic acid at a more rapid rate than at the lower temperatures, but high temperatures are seen to have a much more deleterious effect on the paste than upon the juice. At 10° C. (50° F.) retention is good in both the juice and the paste, even after a storage period of two years.

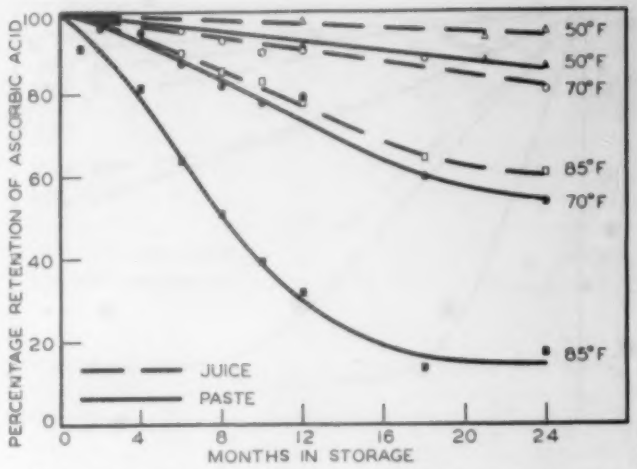

FIG. 1. Retention of ascorbic acid during storage of tomato juice and tomato paste prepared at Cannery A, and packed in 6-ounce (202 x 308) cans.

These results confirm the findings of Hummel and Okey *(7)* whose results show fairly good agreement with ours at the higher storage temperatures. Our paste samples show considerably better retention of ascorbic acid at 21° C. (70° F.) than their samples of commercial paste stored at "room temperature," which reportedly varied from 20 to 25° C. (68 to 77° F.). The retention of ascorbic acid in their room temperature samples of tomato paste agrees more nearly with our samples stored at 29.5° C. (85° F.) indicating, possibly, that the average temperature of their room storage was

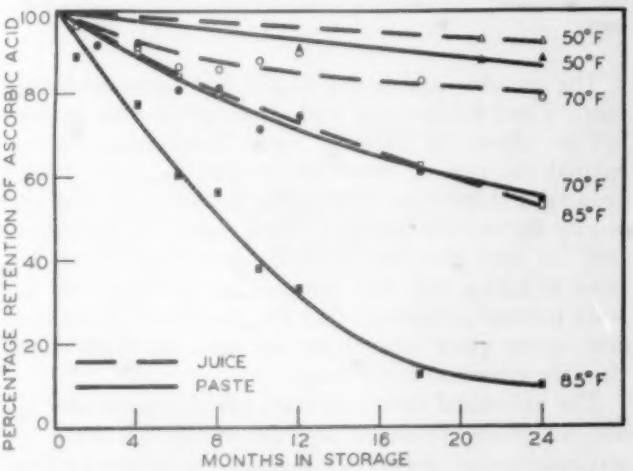

FIG. 2. Retention of ascorbic acid during storage of tomato juice and tomato paste prepared at Cannery B, and packed in 8-ounce (211 x 304) cans.

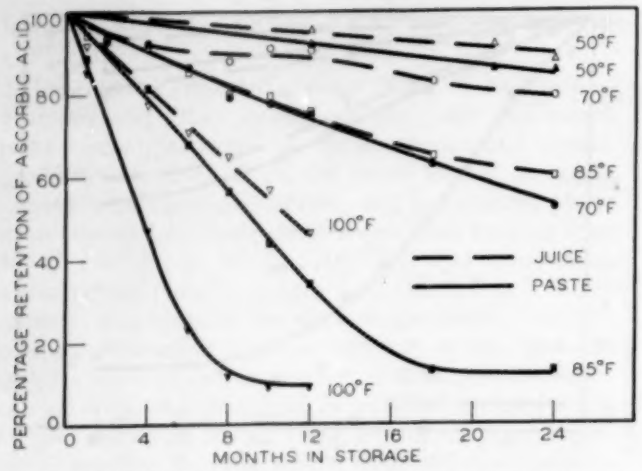

FIG. 3. Retention of ascorbic acid during storage of tomato juice and tomato paste prepared at Cannery C, and packed in 6-ounce (202 x 308) cans.

higher than the reported temperature range would indicate. Our results show that the retention of ascorbic acid in paste stored at 21° C. (70° F.) is about the same as that of juice stored at 29.5° C. (85° F.). Juice stored at 21° C. (70° F.) showed slightly poorer retention than paste stored at 10° C. (50° F.).

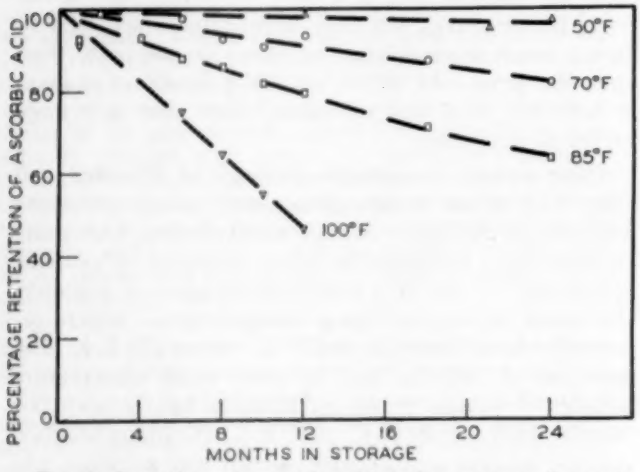

FIG. 4. Retention of ascorbic acid during storage of tomato juice prepared at Cannery D, and packed in No. 2 (307 x 409) cans.

The ascorbic acid found in the juice samples before canning and the ascorbic acid values at the time of storage are shown in Table 1. From these values is calculated the percent retention of ascorbic acid during canning and the time intervening between packing and testing the canned samples. These values do not represent the true canning retention since losses occurring prior to taking the juice samples are ignored. The results indicate, however, that the retention of ascorbic acid in the paste was about the same or slightly less than the retention in the juice.

The individual values for total solids, copper, and pH are not given; however, average values for these determinations are shown in Table 1. The values for total solids and pH are average values obtained from all the samples that were tested. The values for copper are

TABLE 1

Retention of ascorbic acid during canning and initial storage and summary of data on total solids, copper, and pH

Cannery	Product	Ascorbic Acid			Total solids by refractometer	Copper, p.p.m.	pH
		Before canning	At time of storage	Retention			
		mg. per 100 g.		%	%		
A	Juice	19.8	15.8	80	5.8	1.3	4.24
B	Juice	24.0	21.6	90	5.9	1.0	4.34
C	Juice	18.5	17.6	95	5.6	1.8	4.31
C	Fortified Juice	.....	70.5	....	5.8	1.8	4.25
D	Juice	.....	20.4	....	6.8	0.6	4.23
A	Paste	92.6 [b]	77.8	84	27.1	7.0	4.18
B	Paste	107.0 [b]	87.4	82	26.3	4.2	4.23
C	Paste	88.2 [b]	81.4	92	26.7	3.8	4.23

[b] Calculated from values given for corresponding juice samples.

the average of at least three sets of samples stored at different temperatures. Little variation was found in any of these values between individual cans of the same series.

The retention values obtained on the sample of juice fortified with ascorbic acid are shown in Table 2, together with similar retention figures obtained on the samples of unfortified juice. These data show that the level of ascorbic acid in tomato juice has little or no effect on the rate of loss of ascorbic acid. This confirms the observation of Hummel and Okey that tomato juice fortified with ascorbic acid to the level of tomato paste concentration showed no greater rate of ascorbic acid loss than did juice alone.

TABLE 2

Retention of ascorbic acid in tomato juice and in tomato juice fortified with ascorbic acid after storage at 21° C. (70° F.)

Cannery	Initial ascorbic acid,	Months in storage					
		2	6	8	12	18	24
	mg. per 100 g.	%					
A	15.8	....	95.5	93.0	90.5	88.5	81.0
B	21.6	....	86.5	86.0	90.0	83.0	79.1
C	17.6	93.8	....	88.0	90.5	83.0	79.5
C	70.5 [c]	98.5	99.0	93.0	91.5	86.0	81.0
D	20.4	99.0	98.0	93.0	92.6	87.3	82.0

[c] Fortified with ascorbic acid.

The observations of Hummel and Okey that copper plays no significant part in the rate of loss of ascorbic acid gains some confirmation by the observation that the variation in copper results shown in Table 1 bears no relationship to the rate of loss of ascorbic acid during storage.

The retention curves for the paste stored at 29.5° C. (85° F.) and at 38° C. (100° F.) show a definite leveling off after the retention has reached 10-15%, and it would appear that after this minimum level is attained the ascorbic acid values show no further decrease on additional storage. One explanation for this behavior is that non-ascorbic acid reducing substances rather than ascorbic acid may account for these low values.

The Roe, Mills, Oesterling, and Damron *(16)* modification of the original 2,4-dinitrophenylhydrazine method provides, according to Mills, Damron, and Roe *(12)* theoretically the closest correlation possible at the present time between the antiscorbutic biological assay

and the actual chemical analysis of a foodstuff. Interfering reducing substances, if present, are supposed to appear in the diketogulonic acid fraction and, consequently, not to affect the results for ascorbic acid and dehydroascorbic acid.

The above method was applied to a series of samples of tomato juice and tomato paste from cannery C, and to the commercial juice packed at cannery D, at the end of the maximum storage period for these samples. As previously stated, all of these samples had been held in the refrigerator for a period of time before making these tests. The results are shown in Table 3, together with the results of copper and iron analyses run on the same samples. Results obtained by the Loeffler and Ponting method on the same series are included for comparative purposes, although these values were obtained on a different set of cans from those used for the Roe method, and the two sets of results may be influenced to a certain extent by can-to-can variations.

Good agreement was obtained in the amount of ascorbic acid found by the two methods on the samples stored at 10° C. (50° F.) and 21° C. (70° F.). At 29.5° C. (85° F.) and 38° C. (100° F.) the Roe method gave consistently lower results than the Loeffler and Ponting method, but the difference between the two results was not as great as was anticipated in view of the drastic storage conditions to which these samples were subjected. The results indicate, furthermore, that measurable amounts of ascorbic acid were still present in all of the samples. The amount of dehydroascorbic acid and diketogulonic acid in these samples had not reached significant proportions, indicating that these substances were about as unstable as ascorbic acid and did not tend to concentrate as the ascorbic acid decreased.

Except in one instance [the 38° C. (100° F.) paste sample] the iron content of these samples had not increased to a point where it would interfere seriously with the indophenol method. Apparently the 38° C. (100° F.) paste samples used for the Loeffler and Ponting method did not contain as large an amount of iron as those used for the Roe method or the value for ascorbic acid as determined by the indophenol method probably would have been higher.

It might be noted that at the time of the last storage test all of the cans of paste stored at 29.5° C. (85° F.) and 38° C. (100° F.) had lost vacuum and most of them had started to swell. These storage periods for the 29.5° C. (85° F.) and 38° C. (100° F.) paste represent, therefore, somewhat more than the commercial storage life of these particular packs when stored at the above temperatures. On the other hand, all of the samples of paste stored at 10° C. (50° F.) and at 21° C. (70° F.) were in good condition at the end of the storage period.

DISCUSSION

From a comparison of the curves shown in Figures 1 to 4 and the data in Table 2, it would not appear that the different canning variables employed in this experiment had any significant effect on the rate of loss of ascorbic acid during storage. The procedures employed for manufacture of tomato paste in the three plants included in these studies represent the three most commonly used in California for the production of tomato paste. The variations in retention values for ascorbic acid during the canning and first few days of storage indicate that the canning procedure may play a more significant part in these initial losses than it does in the losses during subsequent storage.

Hummel and Okey have presented a detailed discussion of possible explanations for the increased rate of destruction of ascorbic acid in concentrated tomato products over that found in non-concentrated products. In addition to the effects of copper and of the initial level of ascorbic acid, which have already been mentioned in this paper, the above authors have investigated the possible effect of oxygen trapped in the container headspace and in the product. They conclude that the amount of oxygen trapped in the container can not account for the amount of ascorbic acid that was destroyed during storage.

The effect of storage on the ascorbic acid in tomato juice reconstituted from tomato paste was also investigated with the finding that the reconstituted juice lost ascorbic acid at the same rate as juice not previously concentrated. From this they conclude that no substance was produced in the concentration procedure which would accelerate the destruction of ascorbic acid.

TABLE 3

Ascorbic acid, dehydroascorbic acid, diketogulonic acid, iron, and copper values on selected samples of tomato juice and tomato paste [4]

Cannery	Product	Storage temperature	Ascorbic acid Loeffler Ponting method *(10)*	Roe et al. method *(16)*			Iron	Copper
				Reduced Ascorbic acid	Dehydro-ascorbic acid	Diketogulonic acid		
		(° F.)	*mg. per 100 g.*	*mg. per 100 g.*	*mg. per 100 g.*	*mg. per 100 g.*	*p.p.m.*	*p.p.m.*
C	Paste	50	69.7	70.4	2.4	2.4	10.1	4.0
	"	70	42.5	36.8	1.6	0.8	9.5	3.6
	"	85	10.4	4.0	0.2	0.6	15.6	3.6
	"	100	7.5	5.0	0	1.4	390	4.2
C	Juice	50	15.5	15.2	0.8	0.4	3.5	2.2
	"	70	14.0	13.0	0.6	0.2	5.5	1.6
	"	85	10.6	4.8	0	0.3	5.5	2.0
	"	100	8.2	7.0	0.2	0.4	5.3	1.3
D	Juice	50	19.9	20.6	0.4	0.2	5.0	0.6
	"	70	16.7	16.4	0.1	0.4	5.7	0.6
	"	85	13.0	11.6	0.4	0.4	6.0	0.6
	"	100	9.5	7.6	0.4	0.4	5.0	0.6

[4] These samples were stored at 50°, 70° and 85° F. for 24 months and at 100° F. for 12 months, after which they were held at 45° F. until tested.

It may also be concluded that none of the volatile constituents lost in the concentration had a stabilizing influence on ascorbic acid. They also reasoned that on the basis of available data on tomato juice and tomato paste the decrease in pH on concentration of tomato juice to the concentration of tomato paste amounted to only about 0.1 pH unit and, therefore, it was unlikely that pH itself was the controlling influence. The magnitude of this pH change receives confirmation by the data shown in Table 1, in which a direct comparison is available between juice and paste made from the same lots of tomatoes.

Hummel and Okey conclude that the only explanation for the increased rate of loss of ascorbic acid in concentrated tomato products that can be offered at the present time is that ascorbic acid may be destroyed through reaction with the citric acid in the tomatoes. They point out that the concentration of citric acid undergoes more than a four-fold increase in the manufacture of tomato paste, and that if some reaction between citric acid and ascorbic acid follows the mass law, this increased concentration of citric acid would be significant. This hypothesis gains support from the work of Lamden and Harris *(10)* on the browning of ascorbic acid in pure solutions. They have found that ascorbic acid-citric acid solutions containing increasing amounts of citric acid, and heated three hours at 100° C., showed an increased amount of browning and decreased ascorbic acid content with increasing concentration of citric acid.

Although the present work has been concerned with concentrated tomato products, there is no reason to believe that the same principles would not apply to other concentrated products containing ascorbic acid and other organic acids.

Further work is needed on the inter-relationship of ascorbic acid, citric acid, and pH on the rate of loss of ascorbic acid during storage of concentrated food products. Although these reactions have been studied in pure solutions, there is little published information on their effect on actual food products. For example, it would be of interest to know whether partial neutralization of the acid in tomato paste with sodium bicarbonate, which is permitted in the U. S. Food and Drug Standard of Identity for tomato paste, would affect the rate of ascorbic acid destruction in this product.

From a practical standpoint, however, changes in the acid-base relationship in tomato products may be undesirable from a flavor and quality standpoint. From the present data it would appear that low temperature storage of concentrated products offers the best means of maintaining high ascorbic acid retention. The data show that tomato paste stored at a temperature of 10° C. (50° F.) retains a large proportion of its original ascorbic acid content for an indefinite period of time. The desirability of cool storage temperatures for canned foods in general has been emphasized by recent work on vitamin retention during storage *(4)*. It would appear to be even more important that concentrated products such as tomato paste be stored under cool storage conditions.

SUMMARY

Tomato juice and tomato paste were prepared at three commercial canneries from the same lots of tomatoes, packed in the same sizes of containers, and stored at 10° C. (50° F.), 21° C. (70° F.) and 29.5° C. (85° F.) for 24 months, and at 38° C. (100° F.) for 12 months. Ascorbic acid was determined before canning, at the time samples were placed in storage, and at various periods of time during the storage period. Total solids, pH, copper, and iron were also determined on certain samples.

The tomato paste lost ascorbic acid at a more rapid rate than tomato juice at all temperatures. The tomato juice was less affected by high temperature storage than the tomato paste. At 10° C. (50° F.) both tomato juice and tomato paste showed good retention of ascorbic acid after 24 months of storage.

The level of concentration of ascorbic acid in tomato juice had no significant effect on the rate of loss of that vitamin. Minor variations in copper concentration had no effect on the retention during storage, although they may have affected retention of ascorbic acid during canning and initial storage.

Ascorbic acid, dehydroascorbic acid, and diketogulonic acid were determined on certain samples of juice and paste after the maximum storage periods by the method of Roe, Mills, Oesterling and Damron. Relatively minor amounts of dehydroascorbic acid and diketogulonic acid were found in all samples and satisfactory agreement with the Loeffler and Ponting method was obtained on the samples stored at 10° C. (50° F.) and 21° C. (70° F.). Higher results were obtained by the latter method at the higher storage temperatures, but measurable amounts of ascorbic acid were found in all samples by both methods.

Possible explanations for the decreased stability of ascorbic acid in concentrated tomato products are discussed. Low temperature storage appears to be the most feasible method of obtaining maximum retention of ascorbic acid in tomato paste.

Acknowledgments

The authors would like to express their appreciation to Stokely-Van Camp, Inc., Thornton Canning Company, Turlock Co-operative Growers, and Bercut-Richards Packing Co. for their cooperation in providing the facilities and materials necessary for carrying out this investigation.

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Bulk Handling of Flour[a]

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(Manuscript received May 21, 1951)

The problems involved in the bulk handling and transportation of flour are discussed together with some of the recent developments in this field.

The idea of transporting flour in bulk is quite old. As far back as the early thirties General American Transportation Corporation was attempting to design a car for this purpose as well as for the transportation of other food products of a similar nature. Unfortunately, these first attempts resulted in failure. It was soon found that any railway car which required complicated moving parts such as permanent screw conveyors or drag chains was impractical. Freight cars must be as simple as possible and so constructed as to take the terrific impact which occurs during humping. To keep special mechanical equipment in a car in regular railroad operation is not only almost impossible but is extremely expensive and frequently unreliable.

In July 1946 General American again set out to solve the problem of bulk transportation of flour. With the lessons learned fifteen or more years earlier clearly in mind, a car was designed having no moving parts. In order to achieve this end, it was decided after much thought to use pneumatics. In collaboration with the Fuller Company of Catasauqua, Pa., who are manufacturers of pneumatic equipment, General American designed and built after extensive laboratory experimentation its first Trans-Flo* car. Throughout the period from the early thirties to date, the National Biscuit Company had expressed keen interest in this development, and, in fact, was the moving spirit in interesting General American in its latest and successful attempt to solve this problem. While General American was conducting its experimentation, the National Biscuit Company ordered a pneumatic system for their Atlanta bakery and thus provided the facilities for testing the completed car.

We thus had an informal group consisting of Mr. H. E. Wiggin, Vice President in charge of Traffic, and Mr. E. Otocka, Director of Engineering, both of the National Biscuit Company, representing the user; Mr. G. K. Engelhart, Vice President of the Fuller Company, Mr. Phil Hornbrook and Mr. Leo Weller, also of the Fuller Company, who represented the unloading equipment manufacturers; and ourselves, representing the transportation equipment end. We thus had all the principal know-how required to develop a system which would not only perform the function of transporting flour but do it in a manner best suited to the needs of the food industry.

There were four principal problems to be solved.

One, the unloading of the car. It was anticipated that the flour would not come out of a covered hopper car by gravity and that some active means would be required to draw the flour from the car. After considerable study it was concluded that the pneumatic method was the most promising possibility.

Two, the elimination of condensation. The possibility of having undue condensation had been a hazard in all previous attempts to develop a car for transporting flour. After careful laboratory investigation, we concluded that there would be no condensation if the car were completely filled.

Three, contamination. The solution to this appeared to be an all-welded steel car having pneumatic nozzle assemblies permanently attached to the car, plus suitable filters and other details to prevent contamination of the commodity during either loading or unloading.

Four, economics. The elimination of the sack is offset in part by the net rental of the car. Since, however, only one man is required for the unloading of a Trans-Flo car, respectable savings are achieved in the way of labor.

[a] Presented at the Eleventh Annual Meeting of the IFT, New York, N. Y., June 18, 1951.

*Registered Trademark.

The actual savings, as I will show, later must be calculated for the particular conditions such as car turnaround time between mill and bakery, plant layout, and labor rates. In almost every case that we analyzed, the net savings were equal to or greater than the commitment for car rental. But even without any savings, the advantages in sanitation and other intangibles would have warranted the use of the car.

Thus having in mind these four principal problems and their probable solution, we proceeded with the investigation of the bulk handling of flour, first by setting up a full-sized Fuller Airveyor System in our laboratory and a section equivalent to 1/6th of a car. We determined in this laboratory the necessary conditions for the unloading of the car and for the elimination of contamination, and some basic facts concerning the economics of the system. It was impractical to study condensation in the full-sized equipment and therefore this problem was investigated with laboratory-sized equipment. After these studies were completed, an experimental car was built which was first loaded at the National Biscuit Company mill in Toledo, Ohio, in October 1948.

We now have at the present moment 24 cars in operation, the majority for National Biscuit, several for General Mills, and several for Ballard & Ballard Company. Our two demonstration cars are in operation, one transporting Semolina and the other transporting dehydrated alfalfa meal.

So much for the general picture. Specifically, the car shown in Figure 1 is a covered hopper type of car classed by the AAR as "LO." Though the present cars are all stainless steel, the cars which we are now building for American Stores will be of Cor-ten steel, which is a low alloy high tensile material, except that the ceiling area as well as all parts above the level of the flour in the car will be of stainless. Essentially, the car consists of two large compartments, each compartment having six hoppers.

The nozzle assemblies can be seen below the hopper, each nozzle assembly taking care of a transverse pair of hoppers. The car carries approximately 115,000 lbs. of flour. This varies somewhat depending upon the grade of flour, the weather, and the care in loading. As stated earlier, it is desirable to have the car as full as possible.

FIG. 1. An all-welded steel Trans-Flo car used for the transportation of flour in bulk.

FIG. 2. Loading hatch of the car.

We have loaded Semolina at Superior, Wisconsin, when the temperature was —39° F. without any difficulty from condensation. The loading rate is entirely dependent upon the rate at which flour can be made available. Unloading takes about three hours, usually somewhat less.

A view of the loading hatch is shown in Figure 2. The filter, held above the hatch, has a dome to shed any gross particles of dirt and rain. While we do not advise it, the car can be unloaded without any difficulty in the rain. All air going in through the hatch during unloading is filtered.

For loading, various means have been used. We have found most satisfactory an air driven spinner which spreads the flour around and gives a very respectable percentage of loading. Flour can be brought to the disperser by any means desired, screw conveyors, pneumatics, or even a gravity chute. The loading equipment can be as little as $1000 in value or where a large number of cars are involved, the loading equipment can be expanded to a high degree of completeness and costing relatively greater amounts.

The unloading nozzle with the door open is shown in Figure 3. A flexible hose coupling shown here is inserted into the simple slip joint. The material gate is opened with a simple wrench. One wrench only is required to open the loading hatches, the unloading doors and to operate the gates. The unloading nozzle is symmetrical and the car can be unloaded from either side. All air passes through the filter screens. The doors are gasketed and are water tight.

A vibrator is used in unloading flour. This vibrator is a portable one and drops into a dovetail casting welded to the outboard slope sheet of each hopper. Two vibrators are kept on hand usually, and one transferred while the other is being used in the unloading. It takes about 30 seconds to shift from one nozzle assembly to another.

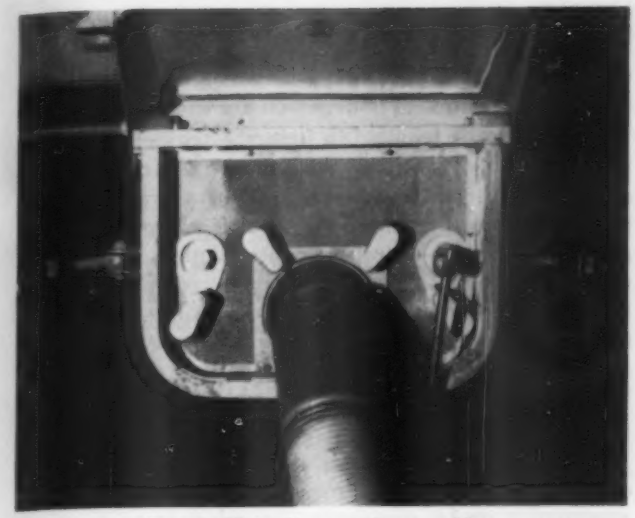

FIG. 3. Unloading nozzle assembly.

In general, out of the original 115,000 lbs., one will rarely find more than ten pounds of flour in the car after unloading. Intelligent but not highly skilled labor is required.

So much for the mechanics. I would estimate that considerably more than 1,000,000 cwt. of flour have been transported in Trans-Flo cars to this date. We have no record of any major difficulty in either the loading or the unloading, since the first three experimental runs were made early in 1949. Even the difficulties experienced during those first few runs were not of a serious nature. Principally, the unloading rate was lower than expected and certain modifications had to be made. In short, despite the packing which flour received when transported on the rails, in every case the combination of pneumatics and light vibration was ample to keep the flour moving at a very satisfactory rate. By keeping the car full, condensation has never been a problem. The attention paid to details such as filtering of the air, proper gasketing of all doors and hatches has eliminated contamination and infestation during transport.

Certain experiments were run by J. C. Dawson at our laboratory in East Chicago, Indiana which showed that some entillation is obtained when flour is handled pneumatically. It is not 100% entillation and is not a substitute for entillators. The test did show, however, that infestation is held down when flour is handled pneumatically. Properly entillated flour, when transported in Trans-Flo cars and unloaded by airveyors, does not become infested, particularly if routine cleaning of the car is practiced. Approximately two to four man hours are generally required to wipe down the car by hand. To my knowledge no Trans-Flo carload of flour has ever been found to be infested nor has any car ever been fumigated.

As for the matter of economics, the Trans-Flo car is leased on a monthly rental basis, in the case of the Cor-ten car with stainless steel trim at $295 per month. Against this rental there is a mileage allowance of 2¼c per mile loaded or empty paid by the railroad to the lessor which allowance is then credited to the lessee's account. Thus, if a Trans-Flo car travels 4500 miles per month, $101.25 mileage allowance is credited against the $295, leaving a net rental of $193.75. Assuming three turn-arounds per month, the net rental charge per trip is $64.58. If the net sack cost after resale is taken at 10c, and 1150 sacks are saved, there is then a net saving, resulting from the elimination of the sacks alone, of $50.42. In addition, assuming 20 man hours to unload 1150 sacks of flour from a box car plus an additional four man hours to take it from storage to use point, plus an additional 23 hours to dump 1150 sacks, plus one hour for disposal of the sacks themselves, it can be seen that to handle 1150 sacks of flour requires forty-eight man hours, whereas to handle 1150 cwt. of flour in the Trans-Flo car would require about six man hours, or a net saving of 42 man hours per Trans-Flo carload.

There is among the other savings, also the matter of shrinkage. We have never been able to pin down the exact amount of physical loss of flour when handled in paper. We feel certain that it is at least 0.5% and probably as high as 1.0%. Since the loss in Trans-Flo cars is practically zero, we feel that the minimum saving in the way of shrinkage is 5½ cwt. per carload. Some of this is due to the elimination of broken bags in the box car, broken bags in handling from box car to storage, and storage to use point, and from dust loss during dumping and perhaps some in the small quantity that is left in each sack after dumping. There are other minor savings, such as saving in freight on the paper sacks themselves. Transported in box cars, 1150 sacks would require a payment of freight on 860 lbs. of paper. The savings which I have given you so far are the savings only at the unloading end. Similar, though smaller, savings are obtained at the mill.

Against these savings the loading and unloading equipment must be amortized. It is difficult to analyze this because conditions vary from plant to plant. Also there is the matter of bulk storage, the cost of which is particularly hard to evaluate because the amount required is primarily a matter of bakery inventory policy. Further, bulk storage simply replaces bag storage. In a new installation, these two may well be a stand off. In an existing installation the net cost of bulk storage depends upon the value of bag storage freed for other purposes. I would say though, that without credit for bag storage and in the average installation where approximately three turn-arounds per month can be made, the net saving will be in the range of from $3,000 to $5,000 per car per year. But I wish to accentuate the point that these savings are in addition to the advantages of sanitation, less unskilled labor required, and no dependency in emergencies on availability of paper or box cars.

With respect to the matter of bulk storage we have proposed, but have never actually built, what we believe will prove to be the simplest type of storage consisting of an insulated cylindrical steel tank or silo with either a Fuller air slide at the bottom for unloading or the same type of hoppers and nozzles that are used in the car. The tank is to be insulated with styrofoam, and here is the principal point—to have a steam heated ceiling which in effect will be a radiant heating panel of the same area as the cross sectional area of the silo. No containing building would be required. These silos would be built in the open, nested together to give the minimum amount of exposed area.

As we already have noted, condensation occurs only as a result of the air space above the flour. It is our contention, well supported not only by our laboratory work but our experience in transporting the flour in uninsulated cars, that if the air space is held to a minimum or if the air space is heated, condensation cannot occur. We feel confident that the combination which we propose will provide a heated air space and condensation will not occur in such a tank. The advantages I think of this type of construction are clear. First, an all-welded cylindrical structure will be free from

any internal structural members which might hold flour and encourage the breeding of insects. The initial cost per cwt. of flour stored would be between $5 and $7 depending upon location, size of tanks, and number of tanks installed at one time. Amortized over a period of say 20 years, this would amount to approximately 30c per year per cwt. If the throughput is taken as 20 times per year, the amortization charges are thereby reduced to 1½c per cwt. Maintenance charges on such a tank should prove to be very low. We estimate less than 250 lbs. of steam per carload per day would be required as the heat load.

There are other perfectly adequate methods of bulk storage in existence today such as tanks or silos of light gauge metal erected inside of conventionally heated buildings, and double wall concrete structures in which the space between the double walls is heated by air. Either of these two accepted methods are perfectly satisfactory and are available. We do advance this other idea as being something for the future which we feel will prove to be better and more economical than existing methods.

There is one other successful method of handling flour in bulk about which I do wish to say a few words at this time. This method is the Tote System. The equipment is manufactured by Tote Systems, Inc., of Beatrice, Nebraska. It has proven to be a very successful and adequate system, and is adapted principally to short hauls, where the cost of return of the empty bins is not excessive. It has been used not only for flour but also for sugar. Essentially, the bins are designed to carry approximately 3,000 lbs. of flour. These bins are loaded and shaken down for maximum capacity in the mills. Then they are sealed, placed upon the trucks and taken to the bakery. At the bakery they are unloaded by means of gravity and vibration right at the use point. The bins themselves can be used as storage. The emptied bins are generally placed upon the same truck, operating between the bakery and the mill, which carries the loaded bins. The Tote System has certain inherent advantages for short hauls and is being used as such most successfully. I can speak very freely and very complimentarily about the Tote System because it covers a field to which the Trans-Flo car is not ideally adapted. The Trans-Flo system is primarily useful for long hauls. It is adapted, however, for short hauls where the quantity to be handled is large. For example, at Ballard & Ballard the haul is a matter of less than one-half mile but several cars are required to handle the large quantities of flour which are used.

When flour is handled in bulk the temperature stays relatively constant. Flour loaded into a Trans-Flo car at say 80° F. and transported at an average ambient temperature in the neighborhood of freezing, will arrive at its destination several days later with a temperature drop of less than 2° or 3°. Flour stored in bulk under the conditions described previously will probably not change in temperature appreciably. Hence, no tempering period is required to bring cold flour up to bakery temperatures. This is a factor which I understand is of considerable importance in cutting down required storage time.

Further, in every handling in bulk by means of either pneumatics or by dispersers, or spinners as they are sometimes called, there is extensive aeration. Each aeration reduces required storage time appreciably although it is not clear exactly how much. Since the temperature is maintained throughout the entire transportation period, the transportation period can be included in the aging time.

It is our belief based on the information which we have gained, that considerable storage time can be eliminated with consequent saving in bulk storage and inventory requirements. The saving in bulk storage is primarily a saving in capital investment. The saving in inventory is a saving in interest charges as well as capital investment. If, say, two weeks can be saved and if each Trans-Flo carload of flour is worth $7000, then at 3% there is a saving in interest alone of $8 per carload.

SUMMARY

Bulk flour handling is sanitary, it provides transportation equipment which is under the control of the user and is available for his use only, and it provides very sizeable savings in both material and labor costs.

Bulk handling is a proven development. There will be continuing modifications, but likely these will be along the lines of engineering development rather than functional development and will not materially change the already realized advantages of bulk storage and transportation.

Pasteurized Fresh Whole Pickles. I. Pasteurization Studies[a,b]

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(Manuscript received May 12, 1951)

Heat penetration and spoilage data were obtained on 24 laboratory and 30 commercial packs of pasteurized fresh whole pickles.

During the past three years heat penetration, spoilage, bacteriological, and other pertinent data were obtained on 54 experimental packs of pasteurized fresh whole cucumber pickles. Twenty-four of the packs of pickles were made in the laboratory and 30 were made in the plants of various commercial pickle packers. The purpose of this investigation was to obtain information on factors which influence the process requirements and quality of this product. The data so obtained have provided a basis for evaluating variations in heating rates, processing values, brine volume to acidity ratios, firmness, and process requirements to prevent spoilage.

According to Fabian and Switzer *(11)*, fresh or pasteurized dill pickles are unfermented pickles made by placing fresh cucumbers in a weak brine, 20° salometer, containing 5.3% salt and about 10 to 15 grains of acetic acid. The desired flavoring is provided by the addition of essential oils, dill weed, garlic, etc. Pasteurization at 73° C. (165° F.) for 30 minutes was recommended. Emphasis was placed on the importance of maintaining an approximately constant ratio of brine to cucumbers, in the jar, in order to maintain a uniform flavor and acidity.

Etchells and Goresline *(5)* reported that controlled pasteurization carried out at 71° C. (160° F.) for 20 minutes or 73° C. (165° F.) for 15 minutes was adequate to kill the bacteria, yeasts, and molds which might cause spoilage in fresh cucumber pickle. According to this pasteurization procedure *(4)*, the jars of pickles are sealed and heated in a water bath until the temperature at the center of the container reaches 73° C. (165° F.). This temperature is maintained in the container for 15 minutes, after which the jars are rapidly cooled to 38° C. (100° F.) by cooling with water. Pasteurization by the above method so reduced the microbial content of the pickles that only the more resistant types of organisms survived, and these tended to decrease during storage. Methods for the bacteriological analyses of pasteurized and unpasteurized pickles and for the determination of keeping quality were outlined. It was concluded that the bacteriological methods described are suitable for determining the correct pasteurizing temperatures and holding period to employ for the preservation of fresh cucumber pickles. Etchells and Jones *(6)* reported that the controlled pasteurization procedure at 73° C. (165° F.) for 15 minutes was adequate for pickle products in classes covering an acid content range of from 4.0 to 17.0 grains acetic acid. It was pointed out that in pasteurizing fresh pickles care should be taken to avoid overheating since this will result in a marked loss in firmness and the possible development of cooked flavors. Pasteurization caused a marked reduction in the number of acid-forming bacteria and yeasts. The surviving organisms were of the heat-resistant spore-forming types.

Etchells and Jones *(7)* showed with pasteurization procedures using temperatures of 49, 54, 60, 66, and 71° C. (120, 130, 140, 150, and 160° F.) applied for 15 minutes, that increasing pasteurizing temperatures brought about corresponding decreases in the number of surviving organisms. Pasteurization at 71° C. (160° F.) was sufficient to destroy both acid-forming bacteria and yeasts in sliced cucumber pickle in 25 ounce jars. Heat penetration data presented by the above authors for pasteurization at 71° C. (160° F.) for 15 minutes when evaluated by the present authors according to the graphical method *(2)* of process calculation were found to have a sterilizing value equivalent to a holding time of 26.8 minutes at 71° C. (160° F.). Etchells and Jones *(8)* presented detailed procedures for the pasteurization of pickles. The importance of controlled pasteurization at 73° C. (165° F.) for 15 minutes was stressed. It was also pointed out that spoilage of improperly pasteurized pickles sometimes does not appear until some weeks after the pickles have been packed.

Procedures for the bacteriological examination of pickles have been described by Etchells and Jones *(9)*. They stated that spoilage of improperly pasteurized pickles is due chiefly to yeasts and/or acid-forming bacteria that survive the faulty heat treatment. Molds and mycoderma scum are factors principally in cases of poor jar closures.

Altenburger and Herold *(1)* described the use of a steam exhaust box for the pasteurization of fresh cucumber pickles. The jars of pickles were brined and put through an exhaust box at a temperature of 99° C. (210° F.). The brine temperature in jars reached at least 66° C. (150° F.). The jars were then capped, pasteurized, and cooled. The authors indicated that if the jars had a brine temperature of 76° C. (169° F.) and a center pickle temperature of 62° C. (144° F.) at the end of the pasteurization treatment the pickles would not spoil. Spoilage to the extent of 39.5% was encountered in jars which had a maximum brine temperature of 73° C. (165° F.).

Bernstein and Epstein *(3)* reported that the use of a quarternary ammonium detergent germicide in washing

[a] Contribution No. 804, Massachusetts Agricultural Experiment Station.

[b] Presented at the Eleventh Annual Meeting of the IFT, New York, N. Y., June 19, 1951.

cucumbers was more effective in reducing the number of microorganisms than was washing in tap water. In terms of pasteurization time at 82° C. (180° F.) the cucumber pickles treated with the germicidal wash required only 15 minutes as compared with 20 minutes for those from the same lot washed only in tap water. On the other hand Fabian and Orloff *(10)* found that tap water or 30 degree salometer brine gave as effective results for washing pickles as did water containing quarternary ammonium compounds.

EXPERIMENTAL

Experimental Packs. During the 1949 season 10 experimental packs of fresh cucumber pickles, in quart jars, were put up in the laboratory, and 9 packs were put up under commercial conditions in three different pickle plants in this area. In 1950 a total of 34 experimental packs were put up as follows: 13 in the laboratory, 14 at two different pickle plants in the New England area, and 7 from various pickle packers in the South and Midwest were put up through arrangements made with the cooperating packers.

The general procedure in making the experimental packs was as follows: The pickles were packed into quart jars in the usual manner. From 10 to 15 pickles (depending upon their size) were placed in each jar. The jars were then brined and sealed. The brine used in the laboratory packs and some of the commercial packs was made up to approximate that used in commercial practice. Variations in acidity of from 12 to 30 grains acetic acid were employed plus 5% salt plus an emulsified Kosher Dill essential oil mixture.[e] From 6 to 8 quart jars of pickles were pasteurized for time intervals of 5, 10, 15, 20, 25, 30, 35, and 40 minutes, respectively, at a temperature of 82° C. (180° F.) in a water bath, unless otherwise indicated. In some cases other pasteurization time schedules and temperatures were used in order to correlate the sterilizing values obtained under various conditions. Immediately after removal from the pasteurizer the jars were cooled under a fine cold water spray.

Within a few hours after being processed one jar from each processing level was examined bacteriologically. The brine was plated out on Difco Nutritive Caseinate Agar. The plates were counted after 72 hours incubation. Counts of acid-forming and peptonizing bacteria as well as total counts were obtained.

The remaining jars were stored at room temperature and examined for spoilage at frequent intervals. Spoiled jars from each process level of each pack were subcultured in an attempt to recover the spoilage organisms.

Heat penetration data were also obtained on jars processed in each run. Two to four thermocouples were placed in the brine in the zone of slowest heating (¼ inch above the bottom of the jar on the vertical axis). In some packs thermocouples were placed in the approximate center of pickles located in the zone of slowest heating. The heat penetration data obtained during this investigation were analyzed to determine the fastest and slowest heating rates encountered. On a basis of the slowest heating jars the lethal or sterilizing value of the process level necessary to prevent spoilage was calculated by the graphical method in terms of holding time at 71° C. (160° F.). With 71° C. (160° F.) as the base temperature, the sterilizing value of process times at other temperatures was calculated and compared in terms of actual holding time at 71° C. (160° F.). This lethal or sterilizing value is given in terms of "F_{160}," with an assumed "z" value of 18° F. F_{160} is the time in minutes required to destroy the spoilage organisms at 71° C. (160° F.), and z is the slope of the thermal death time curve of the organism.

As will be shown later, a holding time (F_{160}) of 36 minutes at 71° C. (160° F.) or its equivalent at other temperatures was necessary to prevent spoilage in some of the experimental packs of pickles. Holding times at other temperatures, which are equivalent to 36 minutes at 71° C. (160° F.) under the above conditions are as follows:

Temperature ° F.	Holding time equivalent to 36 minutes at 160° F.
160	36.000
165	19.100
170	10.080
175	5.330
180	2.740
185	1.460
190	0.792
195	0.414
200	0.218
205	0.115
211	0.054

An indicated equivalent holding time of 2.74 minutes at 82° C. (180° F.), for example, does not mean that a 2.74 minute process at 82° C. (180° F.) is required for a jar of pickles. The derivation of the actual required process time involves an integration of the sterilizing values of the temperature in the jar as it heats up and approaches the pasteurization temperature. Under these conditions, the process or pasteurization time is extended until the integrated sterilizing values are equal and equivalent to 2.74 minutes actual holding time at 82° C. (180° F.) As will be shown later, a pasteurization time of 40 minutes at 82° C. (180° F.) was required to provide this degree of sterilization.

In some of the laboratory packs the pickles were not washed or soaked but were packed just as they came from the field to provide a high bacteria load in the product.

Pickles from each process level of a number of the packs were tested for the presence of the enzyme peroxidase, using guaiacol as a substrate.

Reports have been received from some pickle packers that off or stale flavors may develop in pasteurized fresh cucumber pickles during storage. In order to observe the tendency of these pickles to develop off flavors, taste tests were conducted on all of the packs of pickles after seven to eight months storage. In the 1950 packs the results of these taste tests were correlated with quantitative tests for peroxidase activity.

After seven to eight months storage firmness tests were made on the various packs of pickles with a penetrometer-type jelly-strength tester made by the Chatillon Company, New York, N. Y. For these tests the penetrometer was equipped with a 1/16-inch diameter plunger. In making the firmness test ¼-inch thick cross slices were taken from the center and one inch from each end of the pickle. The firmness in terms of grams pressure to penetrate the slices was determined at three points around the slice, midway between the skin and the central seed core area. Such tests were made on each pickle from one jar, and an average of the results was taken as the representative firmness of the pickles.

Packs were also made in which 20 p.p.m. of mustard oil (allyl isothiocyanate) were added to each jar to see if this compound would decrease the process time required to prevent spoilage.

RESULTS

Pasteurization Time and Temperature Requirements. The results obtained in the experimental packs of pickles are summarized in Table 1. The process time required to prevent spoilage and off-flavors is taken as the next longest process time above the longest process time at which spoilage was encountered. In most cases spoilage occurring within three weeks after packing was characterized by vigorous gas production and cloudiness. Much of the spoilage that developed after this time was characterized by the formation of a white sediment on the pickles and at the bottom of the

[e] Provided by the Magnus, Maybee and Reynard Company.

TABLE 1

Summary of experimental packs of pasteurized fresh whole pickles put up in 1948, 1949 and 1950

Pack no.	Plant [4]	Date	Pasteurization temperature	Pasteurization time and F_{100} value to prevent spoilage		Pasteurization time and F_{100} value to prevent off-flavor on storage		Acidity of ingoing brine
				Time	F_{100}	Time	F_{100}	
			° F.	Min.	Min.	Min.	Min.	%
1	A	8/10/48	187	20	1.1	....	....	....
2	M	8/1/49	180	40	36.0	20	0.7	....
3	M	8/4/49	180	35	21.0	25	2.8	....
4	M	8/8/49	180	35	21.0	20	0.7	....
5	A	8/9/49	180	20	0.7	25	2.8	....
6	A	8/9/49	180	20	0.7	30	9.3	....
7	M	8/12/49	180	40	36.0	30	9.3	....
8	M	8/12/49	180	40	36.0	30	9.3	....
9	B	8/16/49	185	15	0.4	25	4.8	....
10	B	8/16/49	185	15	0.4	25	4.8	....
11	C	8/18/49	180	40	36.0	25	2.8	....
12	C	8/18/49	180	40	36.0	20	0.7	....
13	M	8/19/49	180	40	36.0	40	36.0	....
14	M	8/19/49	180	40	36.0	30	9.3	....
15	M	8/23/49	180	40	36.0	30	9.3	....
16	M	8/23/49	200	20	5.0	21	6.0	....
17	A	8/24/49	180	35	21.0	25	2.8	....
18	A	8/24/49	200	15	2.0	18	3.0	....
19	A	8/24/49	180	40	36.0	....	....	....
20	M	8/30/49	200	15	2.0	24	13.4	....
21	D	5/31/50	165-185	14	....	35	....	....
22	E	6/7/50	185	20	1.1	35	35.2	....
23	F	6/10/50	175	15	0.2	35	12.2	....
24	G	6/9/50	190-200	15	....	30	....	....
25	M	8/8/50	180	40	36.0	30	9.3	0.80
26	M	8/8/50	180	40	36.0	30	9.3	1.20
27	M	8/8/50	180	35	21.0	35	21.0	1.60
28	A	8/10/50	180	25	2.8	30	9.3	1.14
29	A	8/10/50	180	25	2.8	30	9.3	1.54
30	A	8/10/50	180	40	36.0	20	0.7	1.77
31	A	8/10/50	180	25	2.8	15	....	2.93
32	M	8/14/50	180	30	9.3	35	21.0	1.57
33	M	8/14/50	180	35	21.0	20	0.7	1.90
34	M	8/14/50	180	30	9.3	25	2.8	3.00
35	M	8/16/50	180	35	21.0	25	2.8	1.60
36	M	8/16/50	212	18	9.7	15	6.9	1.60
37	A	8/17/50	180	20	0.7	25	2.8	1.99
38	A	8/17/50	180	20	0.7	25	2.8	1.67
39	A	8/17/50	180	20	0.7	20	0.7	1.81
40	A	8/17/50	180	20	0.7	20	0.7	2.94
41	M	8/21/50	180	40	36.0	35	21.0	1.59
42	M	8/21/50	196	28	24.0	28	24.0	1.59
43	G	8/21/50	190-200	10	....	30	....	1.73
44	M	8/22/50	168	55	23.7	40	7.7	1.71
45	M	8/22/50	180	30	9.3	35	21.0	1.71
46	M	8/22/50	211	12	3.5	21	20.2	1.71
47	A	8/29/50	180	35	21.0	35	21.0	1.15
48	A	8/29/50	180	20	0.7	35	21.0	1.54
49	A	8/29/50	180	15	....	30	9.3	2.04
50	A	8/29/50	180	20	0.7	30	9.3	2.94
51	C	9/18/50	180	10	....	40	36.0	....
52	C	9/18/50	195	12	0.7	36	....	....
53	H	9/10/50	185	10	....	25	4.8	....
54	I	9/19/50	180	30	9.3	10	....	....

[4] The various letters designate different packers. Packs put up at the University of Massachusetts are designated by "M".

jar and by occasional clouding of the brine. Jars of pickles showing this type of spoilage have been found from time to time on stored shelves.

Considerable variation in the rates of heat penetration in different jars of pickles was observed. In order to obtain a basis upon which to evaluate the time and temperature requirements for pasteurization, the heat penetration data of jars of pickles from 28 different packs processed at 82° C. (180° F.) were treated statistically in order to arrive at the slowest rate of heating that might be expected. The heat penetration data for each jar were plotted on semilogarithmic paper and defined in terms of "j" and "f_h" values according to Ball *(2)*. Here "j" is an arbitrary factor which, when multiplied by the differences in degrees (° F.) between the temperature of the pasteurizer and the initial temperature of the jar, designates a point of intersection of the vertical line representing the beginning of a process with the extension of the straight portion of the semi-log heating curve, when no time is consumed in bringing the pasteurizing bath to pasteurizing temperature, and f_h is the slope of semi-log heating curve expressed as time in minutes required to traverse one complete log cycle on the temperature ordinate.

The standard error and deviations of the "f_h" and "j" values were determined, and the upper and lower limits taken were based on the "t" value for the 1% level according to Snedecor *(14)*. The average and upper and lower limits of the heat penetration data thus indicated are shown in Figure 1. These data are described as follows:

	j	f_h
Average	0.89	26.0
Fastest heating	0.43	15.6
Slowest heating	1.35	36.4

The above data were in good agreement with the actual data obtained for the slowest and fastest heating jars and exceeded the actual limits by only a small degree.

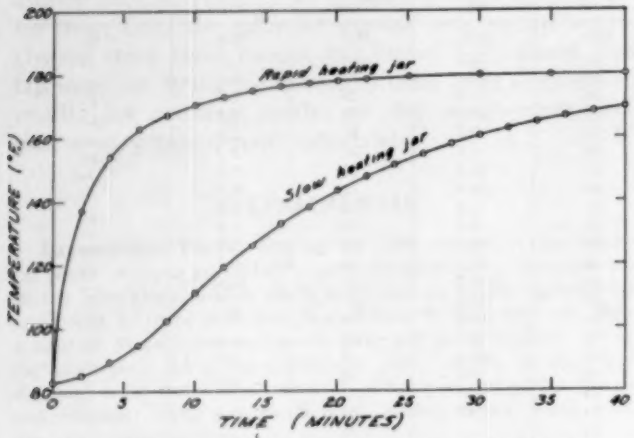

FIG. 1. Heat penetration curves for most rapid and slowest heating jars of fresh whole pickles pasteurized in a water bath at 82° C. (180° F.).

Data based on the slowest heating rates to be expected were used to calculate the sterilizing value (F_{180}) required to prevent spoilage and off-flavor development in the experimental packs as shown in Table 1. On a basis of the available data and the actual spoilage encountered it would appear that a sterilizing value equivalent to 36 minutes at 71° C. (160° F.) with an assumed "z" value of 18 was required to prevent spoilage. On this basis pasteurization times required to provide an equivalent degree of sterilization at pasteurization temperatures ranging from 165 to 211° F. were derived by applying mathematical methods *(2)* and are listed in Table 2. These pasteurization times were adequate

TABLE 2

Equivalent pasteurization times for quart jars of fresh whole pasteurized pickles at different temperatures to provide sterilizing values equal to F_{180} of 36 minutes achieved with 40 minutes process at 180° F.

Pasteurizing temperature	Pasteurizing Time
° F.	*Min.*
165	63.4
170	52.3
175	44.8
180	40.0
185	35.2
190	32.2
195	29.7
200	27.7
205	25.8
211	24.3

to prevent spoilage in the experimental packs pasteurized at different temperatures as may be seen from Table 1. These pasteurization times are based upon a procedure wherein the jars are placed in a processing tank at the indicated pasteurization temperature, the temperature is maintained constant during the pasteurization time, and then the jars are cooled. This procedure differs from the controlled pasteurization procedure as described by Etchells and Jones in which the jars of pickles are heated in a water bath until the temperature at the center of the container reached 73° C. (165° F.). This temperature is maintained in the container for 15 minutes, after which the jars are rapidly cooled to 38° C. (100° F.).

Brine Volume. Data on the brine volumes of 592 quart jars of pickles representing both commercial and laboratory packs were obtained. The results are summarized as follows:

Brine Volume, fl. oz.	Percentage of Jars
8 to 9	5.4
9 to 10	22.8
10 to 11	31.4
11 to 12	27.5
12 to 13	10.6
13 to 14.5	2.3

The above data indicate extremes in ratios (from 3:1 to 9:7) of pickles to brine by volume in the jars. Such variations are difficult to control in practice; yet they can have an important influence on the acidity and flavor of the finished product. Likewise, these variations are a complicating factor in attempting to arrive at minimum pasteurization requirements for this product.

A correlation of the rate of heating (f_h) with the brine volume gave a correlation coefficient of —0.500. Such a correlation is taken to indicate that although there was a tendency for the jars with a large volume of brine to heat more rapidly, the brine volume was not the only factor influencing the rate of heating. The method of packing and the tightness of individual pickles also have an important influence on the rate of heating in the slowest heating portion of the jar.

An analysis of the brine volumes of jars of pickles which spoiled in the experimental packs indicated a general trend towards a higher incidence of spoilage in jars with lower brine volumes. However, occasionally spoilage was encountered in jars with relatively large brine volumes. The tightness of packs of individual pickles with an accompanying slow rate of heating in localized areas was taken as a contributing factor.

Firmness. Pasteurization times up to 40 minutes at 82° C. (180° F.) appeared to have no significant effect on the firmness of the pickles. One series of tests was conducted in a commercial plant in which lots of pickles were pasteurized one, two, and three times, respectively, in a continuous pasteurizer. One pass through the pasteurizer provided a degree of heating approximating 40 minutes at 82° C. (180° F.). The pickles pasteurized two and three times had about the same degree of firmness as those pasteurized once in the usual manner.

The penetrometer method of measuring firmness gave results which were in agreement with subjective biting and chewing tests.

Cooked Flavor. No evidence of so-called "cooked flavors" was observed in any of the packs of pickles. It was concluded that pasteurization treatments within the limits used in this investigation did not overcook the product to the extent of producing adverse flavors. Likewise, in one test where lots of pickles were pasteurized one, two, and three times, respectively, in a

continuous pasteurizer, no cooked flavors caused by over-pasteurization could be detected.

Enzymes and Off Flavors. Reports have been received from some pickle packers that off or stale flavors may develop in pasteurized fresh cucumber pickles during storage. Taste tests were made on the experimental packs of pickles after seven to eight months of storage at room temperature. As indicated in Table 1, the development of such a flavor was prevented or retarded if the pickles were pasteurized long enough. The tendency of the pickles, if not pasteurized sufficiently, to develop an offor stale flavor during storage appears to be related to the destruction of peroxidase and related enzymes. The off flavor is similar to that which is caused by adding a peroxidase preparation to pickles *(12)*. The presence of peroxidase was found to play a role in lowering the quality of the color, flavor, and aroma of processed cucumbers. The effect on quality was more noticeable with samples containing the greater concentration of peroxidase.

Effect of Acidity. The range of acidity normally employed in packing pasteurized fresh whole pickles did not appear to have a significant effect on the pasteurization requirements of this product on a basis of practical observations. Other factors such as tightness of pack, etc., appear to be of greater importance. However, the use of as high a degree of acidity as practical should provide an added safety factor in contributing to a more effective rate of destruction of spoilage organisms during pasteurization as well as in preventing the growth of microorganisms in the product during storage. The observed relationship between the original and equalized acidity and its variation with brine volume is shown in Figure 2.

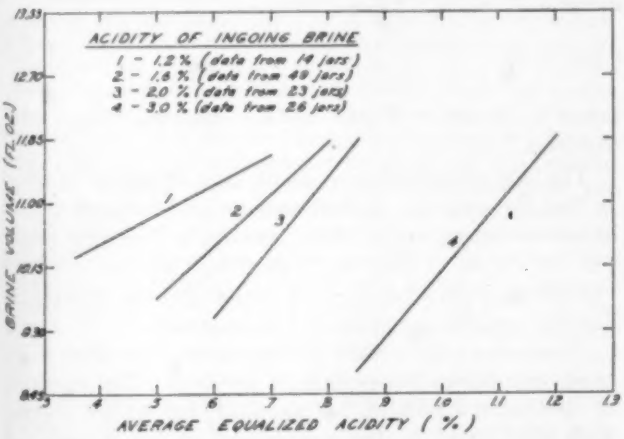
ACIDITY OF INGOING BRINE
1 - 1.2 % (data from 14 jars)
2 - 1.6 % (data from 49 jars)
3 - 2.0 % (data from 23 jars)
4 - 3.0 % (data from 26 jars)
BRINE VOLUME (FL. OZ.)
AVERAGE EQUALIZED ACIDITY (%)

FIG. 2. Observed relationship between original and equalized acidity in brine of quart jars of pasteurized fresh whole pickles.

Relationship of Present Results to Those of Etchells and Jones. The controlled pasteurization procedure as described by Etchells and Jones, which is based on heating the jars of pickles for 15 minutes after the center has reached 73° C. (165° F.) has been followed as standard practice by many pickle packers. The results of the present investigation are in general agreement with the above method so far as the sterilizing value required is concerned, and variations in the product are considered. Data on variables encountered in this product and their effect on quality and pasteurization requirements have been presented.

DISCUSSION

The rate of heat penetration into quart jars of fresh whole pasteurized pickles is subject to considerable variation. An important cause of this variation is the nonuniformity of the product and the way it is packed into the jars. In some jars the nature of the pack may be such as to permit considerable free circulation of the brine, by convection currents during pasteurization, while in others the circulation may be greatly impeded. Also, frequently two or more pickles may be pressed tightly together, thus forming pockets or zones which heat relatively slowly. In order to prevent spoilage the pasteurization procedure should be adequate to destroy potential spoilage organisms which might be present in the localized zones which heat slowly. In determining the rate of heat penetration in this product, every effort was made to take the above variables into consideration.

The equivalent holding time or sterilizing value (F_{160}) at 71° C. (160° F.) was taken as a basis for evaluating the pasteurization requirements for each pack and for calculating equivalent pasteurization time at various temperatures. Such calculations were based upon the conditions of slowest heating as indicated by the data obtained. It is recognized that in a product of this type the indicated sterilizing value may be more severe than that indicated by the heat resistance of the spoilage organisms themselves. However, this apparent discrepancy is necessary in order to provide adequate pasteurization under the variable conditions of heating which were encountered in the packs of pickles under consideration.

Within limits the proportion of brine to pickles affected the rate of heating and the incidence of spoilage encountered. As the proportion of brine to pickles by volume, in a jar, was increased, the rate of heating tended to increase. However, from a consideration of the nature of the product and method of packing it is obvious that the tightness of pack and the placement of individual pickles in the jar may also have an important bearing on heating rates. These factors are important variables that must be considered in the pasteurization of this type of product.

Heat penetration data presented by Etchells and Jones *(7)* for fresh sliced cucumber pickle in 25-ounce jars, pasteurized according to their controlled procedure [center temperature of the jars maintained at 71° C. (160° F.) for 15 minutes], were evaluated in terms of F_{160}. The total heating on pasteurization treatment was found to provide an F_{160} value of about 27 minutes. In the present investigation the required F_{160} value of 36 minutes for quart jars of whole pickles takes into account the greater variation in heating to be expected with whole pickles.

The time and temperatures for pasteurization employed in this study had no significant effect on the firmness or flavor of the pickles.

CONCLUSIONS

Heat penetration and spoilage data were obtained on 24 laboratory and 30 commercial packs of pasteurized fresh whole pickles. As represented by the data obtained a sterilizing value equivalent to an actual holding time of 36 minutes at 71° C. (160° F.) was required to prevent spoilage and the development of off flavors due to enzyme action. Insofar as could be determined by flavor, firmness, and color this degree of sterilization had no deleterious effect on the quality of the pickles.

Acknowledgment

Acknowledgment is due the Glass Container Manufacturers Institute, Inc., New York, New York, for its interest and support in the conduct of this investigation. We also wish to thank the following pickle packers for their interest and cooperation in providing facilities, materials and experimental packs: Silver Lane Pickle Co., East Hartford, Conn.; National Pickling Works, Boston, Mass.; R & S Pickle Works, Boston, Mass.; I. Miller Co., N. Tonawanda, New York; Brown-Miller Co., Wiggins, Miss.; Mount Olive Pickle Co., Mount Olive, N. C.; Budlong Pickle Co., Chicago, Ill.; Squire-Dingee Co., Chicago, Ill.; C. C. Lang and Sons, Freemont, Mich.; and Green Bay Food Company, Green Bay, Wisc.

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Food Engineering as a Profession[a]

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(Manuscript received May 2, 1951)

The food field is a big, fast moving, highly competitive group of industries ceaselessly inventing new and better ways to produce, prepare, process, handle, and distribute its gigantic annual output of 57 billion dollars' worth of foods.

This means, of course, that separate food industries such as your own are constantly pitted against not only their own direct competition but also that of every other industry interested in selling food and allied products. To progress, it has become axiomatic that a close check must be kept on the activities of competitors as well as all developments pertaining to products, processes, and equipment not to ignore consumer preferences and economic influences. There is nothing static about any food industry. We are seeing radical changes in markets taking place almost overnight as consumers are weaned away from conventional food products to those possessing unusual appeal and convenience in the estimate of the buying public. To paraphrase the entertainer's dictum "There is no business like food business."

The one great factor we must keep foremost in mind is that the cadence of development is accelerating and at a bewildering speed. Life literally is changing under our very eyes. Today we have things we did not have yesterday. And what is more important, the rapidity of change is gathering more and more speed.

There was a time when developments depended solely upon new things happening by accident. The curiosity of Benjamin Franklin, for example, led to his playing with electricity for the amusement of his friends. A little later we see the advent of the professional seekers after scientific knowledge, Faraday being among the earliest. Edison was one of the first to organize research groups on a commercial basis. Today we have literally hundreds, if not thousands, of research groups in industry and universities. Constantly, we hear of new organizations of professionals who are brought together by the pressure of events and for the purpose of sharing, discussing, and solving mutual problems.

The impulses of any organized efforts serve to activate the impulses of other organized efforts. Translated

[a] Presented under the title of "Where Do We Go From Here —And How?" to the American Society of Brewing Chemists in Chicago, Illinois, on April 24, 1951.

into more practical terms, this means that competition between individual companies of any given industry is not only accelerated but, in addition, the instinct of self preservation is forcing competition to develop between industries themselves. When we attempt to resolve our discussion in terms of food products, it immediately becomes apparent that competitive forces will be intensified if only by the fact that a human being does have physical limits to his nutritional intake although we know that great numbers still do not receive an optimal dietary.

Perhaps we can best illustrate this vital factor of cadence more graphically by resorting to the historian's device of compressing the time scale. Therefore, in order to make its results more apparent, let's compress time by a million fold whereby a million years become one and a century but an hour. With that sort of scale, you can look back a year or two to the first primitive man picking up an odd-shaped stick or stone and using it as some sort of implement or weapon—also finding that sounds can take on meaning with language appearing.

About a month ago, one of these beings has learned to shape sticks and stones more carefully to better fit his needs and by last week you see the cavemen in their caves drawing diagrams of aminals not too unlike some of the efforts of our presumed ultramodern impressionistic artists—the significance of which escapes me. By the day before yesterday, these primitive drawings (not the ultramodern ones) have begun to evolve into a primitive type of writing with the result that yesterday the alphabet appeared. Speaking as of noon today, it would be about yesterday afternoon that the Greeks were developing their ancient practical arts with the dawn of Christianity appearing at dinnertime last evening. Last midnight the Roman Empire fell and darkness shuts off the picture for a few hours. However, at 7 A. M. the invention of printing by Coster and Gutenberg assured the coming dissemination of knowledge and its enormous encouragement of scientific communication. The first telescope and microscope appeared at approximately 8:30 A. M. while at 9 A. M. Galileo dropped his cannon balls from the Tower of Pisa to find that they fell at the same speed thereby starting a series of interesting experiments contributing to what we call modern science. Bacteria were first observed as we had the beginnings of organic and biological chemistry at 9:30 with those of analytical chemistry appearing about 9:45 this morning. About 10 o'clock was witnessed the start of instrumentation with the introduction of the thermometer and the saccharometer. By eleven o'clock, Pasteur had completed his demonstrations of asymmetric molecules and optical activity in tartaric acid just before he was prepared to explain why Appert had been successful with his food preservation method at 10:30 for, as you will recall, Pasteur not only proved that certain bacteria and yeasts were responsible for wines becoming sour, turbid, and otherwise a total loss but in so doing exploded the former theory of spontaneous generation. The development of commercial refrigeration and its adoption in breweries followed closely on the heels of Pasteur's findings and by 11:15 Koch had established his reputation as the Father of Bacteriology on the basis of his work in a brewing laboratory, incidentally. At 11:20, Dr. Kjeldahl presented his classical method of nitrogen determination and just before 11:30 Jorgensen and Hansen reported their work on the development of pure cultures in the laboratories of the Carlsberg Breweries in Denmark. All this was promptly followed by the revelation that filtration enhanced the benefits of pasteurization by providing better stability and keeping quality permitting widespread shipping of beer.

As the minute hand of our condensed time clock started its upward swing to high noon, telephones appeared on the office walls of more and more breweries where roll top desks were finding their "pigeon holes" becoming outmoded as commercial bottling got under way. About twenty minutes ago, Model Ts were trying out new cement highways as Buicks were abandoning planetary transmissions and with their valve-in-head motors beginning to interest Dr. Midgeley in developing anti-knock gasoline. A few minutes later, rayon, dry ice, cellophane, and urea resins were popping up. Ten to twelve minutes ago Dr. Fleming was producing penicillin in his laboratory in England as air-mail service was being extended all over the United States to be promptly followed by a few established airlines for passengers and traffic with expedited schedules. Crystal sets were being put aside for the radios tuned in on sustained programs transmitted by short wave thereby making the world a unit in communication. About five minutes ago, nuclear fission became a reality as sulfa drugs appeared along with synthetic rubber. Three and one half minutes ago the Atom Bomb exploded over Hiroshima to end World War II as television broadcasting started a debate on the continued popularity of radio. And just before the bell in tower started to ring in high noon, there rushes in the news of a more terrible Hydrogen Bomb along with newer antibiotics, ACTH, and a possible cure for cancer plus mass spectrometers to analyze vapors. And, in passing, let us note that at 11:30, 95% of the bread we ate was baked in the home whereas at noon 95% of our bread was being prepared in commercial bakeries.

The purpose of this imagined flight of factual events is merely to point out that with our present organization of research and development effort, obsolescence is truly treading the heels of utility. In fact, before a modern author can see his manuscript in its published format, it is already outmoded in timeliness particularly in the scientific and technological fields of knowledge. This illustration also points to the urgent necessity of cooperation between the arts and the sciences in order to be enabled to make optimal use of the knowledge that is flooding in upon us as well as that which has already been harvested. Like the Scorcer's Apprentice, we must have this essential cooperation or else we shall fail to stem the deluge threatening to engulf us.

At the very least, we must concede that the necessary consequence of all this developmental effort and fruition can only lead to more rapidly growing knowledge and, as a natural result, to more and more new developments. There is no apparent escape from it.

In order to bring order out of chaos, it is obviously essential to specialize in technological pursuits inasmuch as it is physically and mentally impossible for the hardiest and most intellectual individual to be proficient in a variety of professions today. While in more leisurely days as when he wrote "The Autocrat of the Breakfast Table," Oliver Wendell Holmes could truthfully answer the query as to what chair he occupied on the Harvard faculty by stating: "My dear sir, I do not occupy a chair, I occupy a settee." Today, chemists, biologists, and physicists must take their training in science and mathematics, lawyers in law, physicians in medicine, preachers in theology, and engineers in science and technology. Let us not forget that in so doing, they are all exposing themselves to intellectual growth and academic maturity with no assurance that the inoculation will necessarily take. Those who do mature will be well grounded in the principles involved and thus be enabled to make the necessary applications that their vocations demand. The usual mistake that many students make—and, for that matter, even some of the "old grads"—is in expecting to be able to use all their educational training in solving

all the problems of practice that may come their way. There is a similar fallacy inherent in the thinking of many executives today when they assume that an individual trained in science should be competent in engineering, or vice versa.

Actually, there is an essential difference in the viewpoint and purpose of the engineer and the scientist. Such difference has been obscured by the similarity in subject matter presented in their formal education. Chemists, bacteriologists, nutritionists, and physicists differ from engineers not so much in the academic distance which they have traveled but rather in the fact that they have moved along different roads with occasional intersections and common paths. It is the purpose of science to seek out generalizations pertaining to natural phenomena without any undue considerations of utility. This has been attested time and time again by the experience that the most important advances of science have been made by men impelled by curiosity only—and without thought of any practical application. However, a scientist essentially becomes a technologist when he becomes primarily interested in utility or application. Technology, as the name implies, involves the "study of technics or methods." We recall having read in an old dictionary its definition as "the profession of inventing." However, the technologist is primarily concerned with the practical application of scientific principles which may or may not be concerned with the "design, construction, and operation of systems or plants wherein the analysis and prediction of their controlled performances and costs are provided." Definitely, this latter responsibility is that of the engineer.

The practice of engineering involves as much of art as of science with the art being best acquired through experience. The engineer must perforce come to grips with practical problems. While the pure scientist is freer to work on the problem which interests him the most without any undue consideration of utility, the engineer has to approach his task with the element of utility assigned top priority. Furthermore, engineers are concerned with the expenditure of capital for equipment and plants. Consequently, they have the burden of establishing and realizing both the predicted performance and the operating costs. Engineering, incidentally, involves group activity. Therefore, teamwork is essential to the engineer whereas to the scientist the element of individualistic attainment is oftentimes a more valuable characteristic for success.

A technologist may be concerned with either the scientific or engineering principles to be applied in any given development. To be most effective, he must of necessity have a broad knowledge of the science and engineering involved. His most useful function can be to guide the engineer in applying scientific principles to an operation. However, the engineer cannot afford to emphasize science and analysis to the exclusion of the cost factors nor to ignore the economic significance of the technological principles involved in any planning under study.

An example may serve to illustrate how economic, scientific, and technological forces serve in commercial development. One of the most interesting product success stories of recent years is that of frozen concentrated orange juice.

In a paper delivered at a meeting of the Nutrition Foundation, the late Thomas M. Rector, vice-president of General Foods Corporation, brought out the fact that this modern frozen food specialty was produced by the application of basic discoveries made many years ago. He explained that its success rests on scientific research, sound economic and engineering considerations plus substantial consumer benefits. He listed the following six stimuli leading to its development:

1. A line of frozen food products was being marketed and it was desirable to add another popular item.
2. A surplus of citrus fruit existed and it was desirable to move this crop profitably.
3. The popularity of soft drinks with fruit juice bases requires a large volume of fruit juice concentrates.
4. England during World War II was particularly short of Vitamin C containing foods and our government supplied concentrated citrus juices under Lend-Lease.
5. The engineering developments of drying as well as the low temperature evaporating processes applied to blood plasma led to the thought that delicate food products might be similarly processed.
6. Nutritional knowledge had created a ready demand for highly palatable sources of Vitamin C.

"This product" stated Mr. Rector, "is a very fine illustration of the workings of our free enterprise system and is all the more impressive because, instead of the usual 10 or 15 years from laboratory success to commercial acceptability, the commercial development of the product has been condensed into a 3-year period."

We are all conscious of the fact that for all food processing industries, increasing reliance is being placed upon large scale equipment to handle, process, and distribute foods. The users of such equipment and the processes involved must rely increasingly upon an adequate engineering knowledge and application of the mechanical or physical, the chemical, and above all else the biological requirements which must be provided in effective and efficient food processing. The field of food engineering is so broad that it must be centered in basic sciences as the foundation upon which to develop a reliable concept of food processing. That means that a properly qualified food engineer must not only have a fundamental understanding of the application of science and engineering to the industrial processing, handling, and distributing of foods but also of the arts of producing and preparing foods as well. The biological changes which take place in the industrial processing of foods are of vital importance. Therefore, they must of necessity be carefully considered and analyzed in the light of the chemical and physical changes to be affected.

All food manufacturing involves a series of operations and processes. The methods and problems of all food processors have their similarities regardless of the products being produced. When the separate processing techniques are analyzed critically and objectively, it becomes apparent that they do have common denominators. Actually, the unit operations in food engineering group themselves into fourteen different classifications for which there are probably over two hundred different names. We won't take the time to enumerate and discuss these separate classifications at this time.

What we do want to impress upon you is that of all our food engineering unit operations, that of controlling is fundamental while that of quality control is of paramount importance. The consuming public has become more and more quality conscious for which they will not pay too high a premium. Therefore, in any well engineered food process or plant, the products are handled in such a manner that control over quality can be exercised easily, readily, and economically. This may mean submitting the final products to competent taste panels or the chemical or the bacteriological laboratory or all three. However, the better the designing or planning, the more readily corrective measures can be put into effect without disturbing production unduly.

Quality control assures the establishment and maintenance of uniformity to accepted standards and represents the sum total of a variety of factors involving proper selection of raw materials, careful handling, judicious processing, attractive as well as protective packaging, and effective distribution—all of these predicated upon consistent sanitation, of course. Likewise, quality control is not static but is responsive to changing conditions and standards. Quality is never an accident. It is always the result of intelligent effort. Consequently, there must be a will to produce a superior article. It is, therefore, a gem with many facets.

These observations on quality control are stated as generalizations because time does not permit their detailed exposition. Therefore, permit us to remind you that we have previously stressed the importance of the factors of the rapidity of changes and of the necessity for cooperation among all the professions involved in the solution of production development problems. It is also important to keep in mind that startling as have been the accomplishments of the past, it will not be surprising if they should prove insignificant when contrasted to those to be made in the future. For, no matter how firmly established and successful is the present status, food industries are increasingly dependent upon research and development to retain their places in the competitive struggles of the future.

Yet, as we reflect upon the colossal amount of knowledge which has been accumulated as well as the rapidity with which this enormous storehouse is being further augmented there is great danger of becoming complacently smug. We are reminded of the charge to Babylon administered by the prophet Isaiah who said: *"Thy wisdom and thy knowledge, it hath perverted thee and thou hast said in thine heart, I am, and none else beside me."* But you also will recall that he added a strangely modern note: *"Desolation shall come upon thee suddenly, which thou shalt not know . . . Thou art wearied in the multiude of thy counsels. Let now the astrologers, the star gazers, the monthly prognosticators stand up and save thee from these things."* In other words, if you are troubled with perplexing problems that appear to threaten your future security perhaps you might well give thought to laying such problems before professionals who have a detached point of view. Perhaps you are too close to your urgent tasks to survey dispassionately the bigger problems that a breadth of viewpoint might more readily analyze and more quickly and economically solve.

This is the day of the implemented idea, of organized group thinking which pushes back the frontiers of the physical sciences, finds new knowledge, and then applies it rapidly and effectively to the problems which confront industry. This is the day when enlightened management is on the prowl for new ideas, new inventions, new applications of scientific principles. Such companies are the one that will offer the new products of tomorrow. On the other hand, the management that is satisfied with the *status quo* will not only lose its leadership but possibly even its further existence as well.

Alert industrial management is more than a little concerned with the methods and the product of institutions of higher education and particularly those which emphasize technological education and research. Only so long as industry supports such institutions can industry be asured of its own technological future advancement.

The combined and pooled effort emanating from a partnership of industry and technology will assure the permanency of the food processing industries' ability to create and expand their own usefulness to society, to contribute to the advancement of their own products and services and to the training of their own men. The future of individual food processing companies is largely dependent upon the quality of the personnel engaged in management, operations, engineering, and research. Today there is no established institution exclusively devoted to the study of their engineering problems nor to the replenishment of their manpower with full competency in food engineering. Possibly, the establishment of an organization wherein food and allied industries could collaborate to solve mutual problems could provide industry with a permanently established and organized research and educational facility presently unavailable. It also could provide the food fraternity with an overall engineering research service in producing, preparing, processing, handling, and distributing foods. Such a facility established on the campus of the proper technological institution might be identified as the Institute of Food Engineering.

However, while this suggestion constitutes a dream for possible future development, there still remain opportunities for effective alliances of technology and industry—for "know how" is the province of industry while "know why" is that of technology and education. And if "know why" is to be provided, industry and business will find it necessary to provide the essential support so sorely needed by private education. If privately-supported institutions are going to be forced to relinquish their educational influence because of apathy towards their financial needs, then the nation will be the loser. The holder of the purse always has insisted on saying where the money goes and how it will be spent. If government is to supply the funds, it will exert its inevitable control in so doing. This applies to ideologies as well as to the material ingredients required in the educational and research development process in the advancement of your own profession and your own industry.

Improvement of Cocoa-type Coatings for Use in Army Rations[a]

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(Manuscript received April 27, 1951)

A cocoa-type coating for use on confectionery rations that will withstand temperatures up to 49° C. (120° F.) for long periods of time and at the same time cannot be differentiated in palatability from regular fine chocolate coatings was developed. Previous use of these cocoa-type coatings made with fats of high melting points in the 49° C. (120° F.) range gave undesirable paraffin or waxy tastes. Low melting point fats were undesirable because of their tendency to bleed out, bloom and stick to the wrappers. Non-ionic surface active agents "emulsifiers" were employed in the development of these new, stable, bloom resistant, and highly palatable summer type coatings. The vegetable fats with the emulsifiers added had a tendency to upgrade the melting points of these fats, i.e., these coatings could stand higher temperatures than the predetermined melting points of the vegetable fats used. On the other hand, the coating without the emulsifiers broke down at the temperature of the predetermined melting points of the vegetable fats used. The addition of non-fat milk solids to the coating was found to aid in the palatability also. Another advantage of the added emulsifiers is that they keep the coating from sticking to the wrappers and eliminate the greasy feeling associated with the use of hydrogenated vegetable fats.

The extensive use of fats and oils in confectionery products for the Armed Forces of the United States has naturally caused more attention to be focused on the structure of these fats. The Quartermaster Corps has been interested from the standpoint of the shelf life of coated candy bars used in various rations. This paper on cocoa-type coatings is the result of cooperative research of the General Products Division of the Quartermaster Food and Container Institute and the Research Laboratories of the Paul F. Beich Company.

The number and types of fats and oils are indeed impressive and we shall limit ourselves to natural vegetable oils and fats used in coatings for candy bars. These vegetable oils and fats are mixtures of triglyceryl esters of the fatty acids. An oil or fat by itself usually contains a number of these esters in various percentages. Chemically there is very little difference between fats or oils, although physically, there are differences; oils are liquid at low tempertures, fats are liquid at high temperatures. The term "fats" in this article implies solid or liquid triglycerides (oils or fats).

In the use of these fats in confections, especially in the production of coatings, the melting points and softening agents are very important. It must be borne in mind that, whether these fats are natural or hydrogenated, they are mixtures of various glycerides and usually do not show sharp melting points. Therefore, the term "melting point" does not imply the same characteristics that it does with pure substances of a definite crystalline nature. Fats first gradually soften and shrink in volume before they become completely liquid. Many wonder why there is a difference in melting and softening points observed by chemists working in separate laboratories. The reason for this is that an analyst can duplicate his own results if he uses his own uniform procedure, but there are many variables in procedures for fat analysis. The melting point must be defined by the specific conditions by which it has been determined and is usually the temperature at which the fat becomes perfectly clear and liquid, whereas the softening point is the temperature at which the fat softens or becomes sufficiently fluid to slip or run. The capillary tube, open tube, and the Wiley methods are used for determining softening or melting points. The melting points referred to in this paper were determined by the Wiley and open tube methods, which are described in any standard food analysis text *(3)* or the Official and Tentative Methods of the American Oil Chemists' Society.

The cocoa butter used in chocolate is especially suitable for coating because it possesses a comparatively low melting point which is very much sharper than most fats in this low range. Also, in the solid state it is somewhat brittle and not very greasy to the touch. This is due to the particular physical and chemical properties of the glyceride structure of the fat, i.e., the high percentage of monooleodisaturated glycerides. Don't be alarmed as this is not an article on the component glycerides of natural fats. The chemistry of the saturated and the unsaturated fatty acids is very complicated. There are many excellent texts *(2)* on edible fats and oils that go into physical and chemical properties, classification, etc., if one is interested in this phase of chemistry.

The Armed Forces require cocoa-type coatings which will stand up for long periods of time at temperatures up to 49° C. (120° F.) for use in desert and tropic areas. These coatings must not only remain stable in these high temperatures and not stick to the wrappers, but must be palatable and nutritive as well. Previous use in these cocoa-type coatings of fats with softening or melting points in the 49° C. (120° F.) range, which will not melt at body temperature, gave an undesirable paraffin or shortening taste *(1)*. The use of low melting

[a] Presented at the Eleventh Annual Meeting of the IFT, New York, N. Y., June 19, 1951.

point fats which bleed out in hot weather resulted in a grey, unpalatable, sticky coating. Even though agents could be added to cocoa butter in regular chocolate coatings to cause them to resist a limited amount of heat, the very low melting point of cocoa butter causes it to bleed at relatively low temperatures.

In order to make the "summer-type" coatings "hardened" oils are used. These hardened oils are hydrogenated vegetable fats which are made by passing hydrogen through the heated oils in presence of a suitable catalyzer, usually under pressure. These fats have heat-resistance properties and their eating qualities are very much improved by hydrogenation. These hydrogenated fats undergo a complete change in chemical and physical properties.

In the development of a stable coating for candy bars, we started by testing the properties of these hydrogenated vegetable fats that are used in summer coating with combinations of various surface active agents or emulsifiers. Non-ionic surface active agents which we will call emulsifiers were employed in the development of a stable summer-type coating. These emulsifiers are complex esters or ester-ethers, their chemical starting points being hexahydric or polyhydric alcohol esters which may be fatty acid esters of glycerol, sorbitol, glycols, etc. These non-ionic surface active agents do not ionize in water as do the anionic and cationic surface active agents.

To select the most useful and desirable emulsifier for chocolate-type coatings, the answer lies in the correct hydrophilic-lipophilic combination which must also have the best general chemical and physical properties that will be compatible with the various components that make up the coatings. Hydrophilic (polar) means water-loving, water-attracting or water-soluble and lipophilic (non-polar) means fat-loving, fat-attracting or fat-soluble. It is possible for an emulsifier to love fat and not hate water and vice versa. Unlike human love, the emulsifier love can be weighed and be expressed in numbers.

Generally the hydrophilic character of the emulsifier is supplied by the free hydroxyl and oxyethylene groups, while the lipophilic portion is found in the long aliphatic carbon atom chain of the fatty acid or fatty alcohol. The emulsifiers in any ester range will vary in freezing points, melting points, have wax-like or oily properties, vary in solubility or dispersibility, etc. Thus, the emulsifiers not only emulsify, but can disperse, suspend, and thicken coatings.

The above outline on the general properties of emulsifiers will indicate the problem in picking out the best single or combination of emulsifiers to be added to the coating with hydrogenated vegetable fats to overcome the problems that have been encountered previously. In our work we felt that a certain hydrophilic-lipophilic balance was necessary for the emulsifiers to be used, also, their physical and chemical properties had to be satisfactory and also be compatible with the various components of the coating. We were searching for a combination which would be polygamous (poly—much, plus gamos—married). Yes, a polygamous emulsifier which could be married to every component of the coating.

First we started with the following vegetable fats from high lauric sources as they have been shown from previous tests to have the best properties from the standpoint of resisting rancidity.

Vegetable Fat	Melting Point, ° F.	Softening Point, ° F.
X	114.36 to 120	99
Y	108 to 113	97.7
Z	98.8	86

With these vegetable fats Y & Z with different predetermined melting points and softening points were incorporated various percentages and combinations of emulsifiers and these were observed at high temperatures and high relative humidities.

Many emulsifiers and combinations of emulsifiers were rejected because of their physical or chemical properties, some gave the coating a bitter or rancid taste or turned rancid on shelf-life tests, and others were too oily or waxy. Many were rejected since they showed no evidence of improvement of coatings. Therefore, we are listing only the combinations of emulsifiers which gave us the many improvements we were seeking in a coating for the Armed Forces. The list of emulsifiers used included the following:

Span 60 (sorbitan monostearate, S60),[b]
Span 65 (sorbitan tristearate, S65),
Tween 60 (polyoxyethylene sorbitan monostearate, T60),[b]
Tween 65 (polyoxyethylene sorbitan tristearate, T65),
G1086 (polyoxethylene sorbitol hexaoleate),
PG400M (polyethylene glycol 400 monostearate),[c]
C1000M (Carbo-wax 1000 monostearate),
MGM (monoglycerol monostearate), and Lecithin.

Used in combinations or alone, these emulsifiers indicated the following order of effectiveness in improving the resistance to heat:

No. 1. 1% of a 50-50 mixture of S60 and T60,
No. 2. 0.25% S60, 0.25% T60 and 0.1% G1086,
No. 3. 1% of a 60-40 mixture of S60 and T60,
No. 4. 1% of a 50-50 mixture of S65 and T65,
No. 5. 0.5% of PG400M and 0.5% C1000M,
No. 6. 0.1% MGM and 0.3% lecithin, and
No. 7. 0.5 lecithin.

The Y coating with lecithin or mono glycerol stearate (No. 6 or No. 7) will pass the old QM standards when used in summer coating that is, to withstand 38° C. (100° F.) for two hours and when cooled to 21° C. (70° F.) for one hour will not stick to the wrapper. By the addition of 1% of a 50-50 mixture of Span 60 and Tween 60 (No. 1) to the Y cocoa-type coating it will upgrade this fat to stand up for 96 hours at 49° C. (120° F.). Y coatings without these emulsifiers will break down under such conditions.

[b] Trademarks of Atlas Powder Co.
[c] Manufactured by the Emulsol Corp. and Glyco Co.

Similarly, by the addition of 1% 50-50 Span 60 and Tween 60 to coatting Z it will upgrade this fat to pass the old QM test as used in a summer coating although in a 96-hour test at 38° C. (100° F.) it will begin to break down. The coating without emulsifiers will not meet the old QM test and breaks down completely at 96 hours at 38° C. (100° F.).

Number 2 almost equaled the performance of No. 1; it did show a lowering in viscosity due to G1086. G1086, being an oleate, needs further study as oleates have a tendency to turn rancid on storage. Number 3 and No. 4 gave good results but were not equal in overall performance to No. 1 or No. 2.

Number 5 showed some improvement over No. 6 and No. 7, but did not compare with No. 4. The above tests were run on summer-type coating having the following formula:

Cocoa powder (10% cocoa fat)	7.5%
Fat (all vegetable)	32.0%
Vanillin (1 oz.)	0.0625%
Spans 60	0.5%
Tweens 60	0.5%
Sugar	59.4375%

It is a known fact that non-fat milk solids increase the shelf life of summer-type coating and produce a coating free of the shortening taste. Production formulas for two types of summer coating with non-fat milk solids found in the new QM specifications are as follows:

Component	Dark-sweet type percent by weight	Light-sweet type percent by weight
Cocoa powder (10-14% cocoa fat)	not less than 17.5	not less than 7.5
Non-fat milk solids	not less than 12.0	not less than 12.0
Added fat (110°-114° F.)	not less than 31.0	not less than 30.0
Lecithin	not more than 0.2	not more than 0.2
Sorbitan monostearate	0.5	0.5
Polyoxyethylene sorbitan monostearate	0.5	0.5
Sugar	not more than 38.0	not more than 49.0
Salt (per 100 pounds of coating)	not more than 2 oz.	not more than 2 oz.
Vanillin (per 100 pounds of coating)	not less than 1 oz.	not less than 1 oz.

To summarize the above results, it was found that combinations No. 1 or No. 2 of emulsifiers produced an unusual and unexpected result. The vegetable fats with the emulsifiers added had a tendency to upgrade the melting points of these vegetable fats, i.e., these coatings would stand higher temperatures than the predetermined melting points of the vegetable fats used. On the other hand, the coating without the emulsifiers broke down at the temperature of the predetermined melting points of the vegetable fats used. The addition of non-fat milk solids to the cocoa-type coating resulted in confections which not only withstood higher temperatures, but at the same time eliminated the waxy, shortening taste. Even though the melting point of the fats used in the cocoa-type coating is higher than body temperature, the emulsifiers tend to incorporate this fat into a creamy mass which when eaten with the centers of the various bars, produces a very palatable and nutritive type confection. Another advantage is that these emulsifiers prevent the coating from sticking to the wrappers and

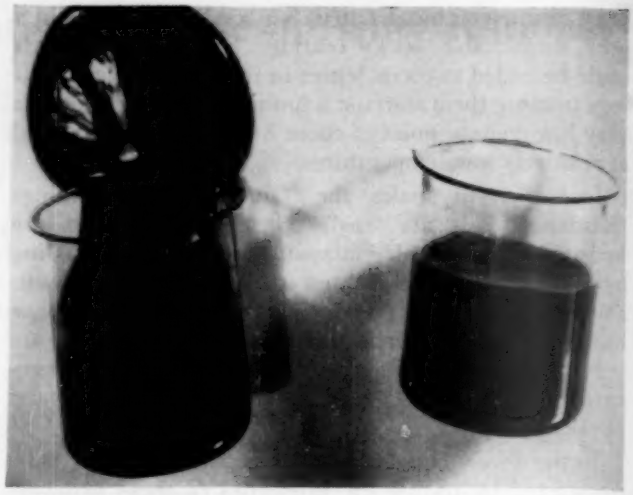

FIG. 1. Ten seconds flow of QM type coating from beakers placed horizontally after coating had been subjected to 120° F. for 96 hours. Left: prepared with emulsifiers (1% of a mixture of 50-50 Span 60 and Tween 60; right: prepared without emulsifiers.

eliminate the greasy feeling that is so often associated with the use of hydrogenated vegetable fats.

This upgrading effect which withstands the higher temperatures is no doubt due to the correct polygamos-hydrophilic lipophilic balance emulsifiers. It loves and tolerates water, fat, protein, and at the same time disperses, suspends, and thickens. It is a polygamous "shotgun" wedding.

Thus the shelf life and palatability of Quartermaster cocoa-type coatings have been improved and these improvements have been incorporated in the new revision of Quartermaster specifications on confectionery products.

Since these improvements on cocoa type coatings, tests were also under way to improve the moulded Enriched Sweet Chocolate Discs as they do not have the necessary shelf-life requirements. Generally, up to 3% cocoa butter can be added to hydrogenated coconut oil coating without effecting gloss or texture of the finished confection. The No. 1 emulsifier combination as used in cocoa type coatings gave the improvements necessary to incorporate the high percentage of cocoa butter found in the chocolate liquor when used with hydrogenated coconut fats. The following formula of a chocolate type coating for moulded Enriched Chocolate Disc meets the rigid Quartermaster requirements.

Sugar	50.33%
Hydrogenated coconut oil (110-114° F. m.p., Wiley)	16.60%
Whole milk solids	16.00%
Chocolate liquor (54% cocoa butter)	17.07%
Span 60	0.5%
Tween 60	0.5%
Thiamine chloride, 12 mg. per oz.	

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The Effect on the Flavor of Strawberry Preserves Caused by Partial Replacement of Sucrose With Other Sweeteners[a, b]

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(Manuscript received May 3, 1951)

[b] A flavor analysis was conducted on strawberry preserves, prepared on a laboratory scale, with partial replacement of sucrose by corn syrup solids and dextrose monohydrate. Findings show that differentiation in flavor between all-sucrose samples and the replacement samples was possible. Triangular taste tests and Flavor Profile analyses were used to detect and measure the differences. The flavor characteristics on which these differences were based are given.

It was the purpose of this study to ascertain if physical and flavor differences could be detected between strawberry preserves sweetened entirely with sucrose and with sucrose partially replaced by corn syrup solids or by a commercial dextrose monohydrate. Strawberry preserves were chosen because they are the most popular preserve *(1, 6)*, and all experimental samples were made in accordance with Standards of Identity for Fruit Preserves *(3)*.

PREPARATION OF STRAWBERRY PRESERVES

Two series of experimental batches of preserves were prepared in the laboratory from frozen strawberries, using the same ingredients, except for sweeteners. In the first series, corn syrup solids were substituted for 10, 15, 25, 35, and 50% of the sucrose. The second series was identical, except that dextrose monohydrate was used to replace the sucrose at each level. The preserves were prepared in several batches each including an all-sucrose sample which was used as a control. Control samples from each batch within a series were checked for flavor differences and none were found.

PHYSICAL CHARACTERISTICS

All batches were found to have at least 68% total solids, as measured by Abbé-type refractometer, and the pH of the preserves showed that there was no correlation between the pH and the percent replacement of sucrose by corn syrup solids or dextrose. The set was determined by visual examination, and all batches were noted to be of a "good" set.

Color comparisons on the freshly made samples were made by two methods: color transparencies were taken and a color dictionary was used *(5)*. The findings showed that there was no significant variation in color between preserves sweetened entirely with sucrose and with partial replacement of sucrose by dextrose and by corn syrup solids.

After holding at room temperature for one week, the 50% dextrose batch presented a mottled appearance due to crystals shown by chemical tests to be dextrose. Such crystallization was later noted at the 35% level but not at any lower replacements.

FLAVOR ANALYSES

Triangular taste tests were run on all the preserves, when fresh and after holding at room temperature, in an effort to determine at what levels of replacement, if any, the partial replacement of sucrose by corn syrup solids or by dextrose could be detected by a trained taste panel. The procedure for triangular taste tests followed that of Helm and Trölle *(4)*, and significance of the findings was determined from the table of Probability in Triangular Taste Tests prepared by Roessler, Warren, and Guymon *(7)*, and based on the Chi square method.

Three coded samples of preserves in small glass beakers were presented to the individual panel members in a quiet, odor-free room. Two of the samples were identical, being taken from the same lot number, while the third sample was odd, having a different sugar composition. Each test always included at least one control sample. The members were asked to select independently the odd sample and to say how it differed. The panel room was illuminated with red lights so that color differences could not influence the tasters' selection; judgments were based on odor and flavor differentiations.

To complement the findings from triangular taste tests, Flavor Profiles *(2)* for the corn syrup solids and dextrose preserves in comparison with their all-sucrose controls were made. This is a semi-quantitative method of analysis, designed to express and describe the characteristic notes of both aroma and flavor, their order of appearance and their intensities. The resulting Profiles were used to analyze flavor differences among the preserves, whereas the triangular taste tests primarily indicated that differences were or were not detectable.

RESULTS

Results for Corn Syrup Solids. The replacement of sucrose by corn syrup solids was detected in triangular taste tests by the flavor panel at the 15% level, but not at the 10% level, for both the fresh and stored preserves. These results are shown in Table 1. Holding the pre-

TABLE 1

Taste panel results for triangular taste tests for the corn syrup solids series

Percent replacement of sucrose by corn syrup solids	Number of tastings	Number differentiated
Freshly made		
10	38	17
15	40	21*
25	66	33*
35	71	37*
50	35	19*
Held eight weeks		
10	28	14
15	30	16*
25	30	16*
35	20	13*

*Significant, probability level at least 0.05.

[a] Presented at the Eleventh Annual Meeting of the IFT, New York, N. Y., June 19, 1951.

[b] This investigation was sponsored by Sugar Information, Inc.

serves for approximately eight weeks at room temperature did not appreciably change the flavor characteristics of the preserves.

In telling why they found the odd sample different, panel members said that the 100% sucrose sample was sweeter, less sour and bitter, and more like the natural fruit than were the replacement samples. These findings of the triangular taste tests were amplified by the Flavor Profiles.

The Profile for the freshly made preserves, Table 2, shows that the sucrose sample had a lower sour note in flavor-by-mouth, a higher sweet note, and a higher "syrupy" aroma note. "Syrupy" refers to a note of

TABLE 2

Flavor Profiles of strawberry preserves for the corn syrup solids series [b]

Freshly made			
	Percent replacement		
	0	15	25
Aroma			
Amplitude	2	1½	1½
Fruit	1½	1	1
"Synthetic Fruit"	0	½	1
Syrupy	1½	1	1
Sour	1	1	1½
Flavor-by-Mouth			
Amplitude	2	1½	1½
Fruit	1	1	1
"Synthetic Fruit"	0	½	1
Sweet	2½	2	2-1½
Sour	1	1-1½	1½
Astringent	1	1	1

[b] 0 is not detectable, 1 is slightly strong, and 2 is moderately strong.

sweet fragrance, plus slight burntness typical of cooked sucrose solutions.

Moreover, the panel found that the "fruity" note also was highest in the aroma of the sucrose sample, and in both aroma and flavor there was an absence of the "synthetic fruit" character, similar to C-16 or so-called strawberry aldehyde (ethyl methylphenylglycidate). Notice that the fruit note is the first note perceived (Flavor Profiles report notes in the order perceived) and that the all-sucrose sample had a higher amplitude or total flavor than the replacement packs. An astringency commonly noted in strawberry preserves did not vary with the replacements and was considered to be a characteristic of the fruit itself. The sweetest sample was that made with sucrose alone.

The Profiles of the "aged" preserves showed little change from the fresh preserves. The 100% sucrose sample remained the highest in the fruit characteristic and continued to lack any synthetic fruit notes.

Results for Dextrose Monohydrate Series. The lowest level of replacement detected by the flavor panel in triangular taste tests run on the dextrose series was 25% in both the fresh and stored preserves. Data for this series are given in Table 3. Retaining the preserves for approximately six weeks at room temperature did not make a lower differentiation possible, although a new bitter note was found in the replacement packs.

TABLE 3

Taste panel results for triangular taste tests for the commercial dextrose monohydrate series

Freshly made		
Percent replacement of sucrose by dextrose monohydrate	Number of tastings	Number differentiated
10	19	10
15	20	9
25	20	13*
35	31	16*
50	20	14*
Held six weeks		
15	20	8
25	20	13*

*Significant, probability level at least 0.05.

Flavor Profiles of the dextrose preserves followed closely the results of the corn syrup solids series. Again, the all-sucrose sample was highest in total aroma, total flavor, fruitiness, "syrupy," and sweet, and lacked "synthetic fruit" notes found in the replacement preserves.

Holding the preserves showed an increase in sour and "synthetic fruit" and the appearance of the new bitter note, found also by the triangular taste tests. The sucrose control sample was again found to have more "natural fruit" flavor and was sweeter than the dextrose preserves.

SUMMARY

An effect on the flavor of strawberry preserves caused by the replacement of sucrose was detected in those samples containing 25% or greater substitutions of a commercial dextrose monohydrate and in those samples containing 15% or greater substitutions of corn syrup solids for sucrose. Differentiation was made at the same replacement levels for fresh and stored preserves. Triangular taste tests and Flavor Profile analyses were used to detect and measure the differences. Examinations of the physical characteristics revealed no correlations between replacement of sweeteners and differences in physical characteristics. Crystallization of dextrose was noted in preserves containing 35% or more of commercial dextrose monohydrate.

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A Survey of Meat Processing Methods Used in Frozen Food Locker Plants[a]

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(Manuscript received May 3, 1951)

Results of questionnaires sent to 11,074 frozen food locker plants concerning methods used in the processing of meat are reported. Methods of freezing, wrapping, and curing meat used in frozen food locker plants are discussed.

There are approximately eleven and one-half thousand frozen food locker plants in the United States, most of which freeze, cure, and store meat. As a part of a comprehensive study of processing in relation to preservation of quality and nutritive value of meats, a country-wide survey was made in the spring of 1949 to determine the most generally used methods of freezing, curing, smoking, and storage.[b] Frozen and cured meats produced by these typical methods will be obtained for laboratory analysis, to determine the differences in their quality and nutritive value. Analyses will include such factors as chemical composition, organoleptic quality, bacteriological characteristics, and biological value of protein. Later these typical methods will be duplicated under controlled, experimental conditions, using meats from animals of known history and feeding. Meats so treated will be analyzed for the same components as were the typical samples obtained from the locker plants. Finally, based on the results of this work, effort will be directed toward devising and developing new or improved methods which will make possible better retention of quality and nutritive value under locker plant processing conditions. This present paper is concerned only with presentation of data on the typical methods of processing used in locker plants.

In conducting the survey the Bureau of Agricultural Economics, in cooperation with the Bureau of Animal Industry, mailed 11,074 general questionnaires concerning methods of processing, to frozen food locker plant operators. Approximately 51% (5,596) of the operators responded. Analysis of answers to this questionnaire showed which locker plants were concerned with freezing, dry curing, brine curing, or smoking and storage of meat. On the basis of this information, a proportional sample of plants carrying out a specific operation, were sent a second questionnaire designed to obtain details of methods used in curing, freezing, and storing meat. Returns on the second questionnaire were over 74%.

[a] Presented at the Eleventh Annual Meeting of the IFT, New York, N. Y., June 20, 1951.

[b] Survey made by Division of Special Farm Statistics, Bureau of Agricultural Economics, Washington, D. C. Substantial assistance was given by Emerson M. Brooks and L. Kathleen Stewart in the preparation of the questionnaires, coding and tabulation procedures.

MAGNITUDE OF THE INDUSTRY

The growth of the frozen food locker plant industry from 1908 through 1950 is shown in Figure 1. Growth was slow until 1930, definitely became established during 1931 to 1935, and grew rapidly thereafter with peak growth during the year 1946. The data in Figure 1 for the years 1938 to 1950 were obtained from the magazine *Ice and Refrigeration (1)*. Iowa leads all other states in total number of locker plants with 875 plants, followed by Washington with 725, Montana with 659, and Wisconsin with 653. The frozen food locker plants with the greatest average number of lockers are found in West Virginia with 748 lockers per plant, in Pennsylvania with 713, in Oregon with 711, and in Maryland with 707. Figure 2 shows that the greatest number of locker plants have from 200 to 500 lockers, with a few plants having only 50 lockers and a limited number having from 1,000 to 4,000 lockers or more.

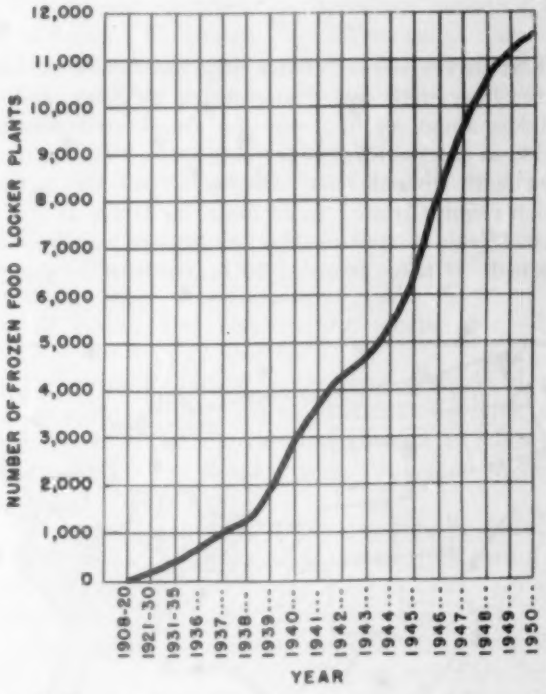

FIG. 1. Growth of the frozen food locker plant industry from 1908 to 1950.

PROCESSING METHODS IN USE

In the frozen food locker plant industry 93% of the plants freeze meat, 73% store cured meat, 53% cure meat—25% brine cure and 40% dry cure.

Brine and dry curing are carried out in locker plants in almost every part of the country; however, as shown in Figure 3, dry curing predominates in the Southeastern and South Central States.

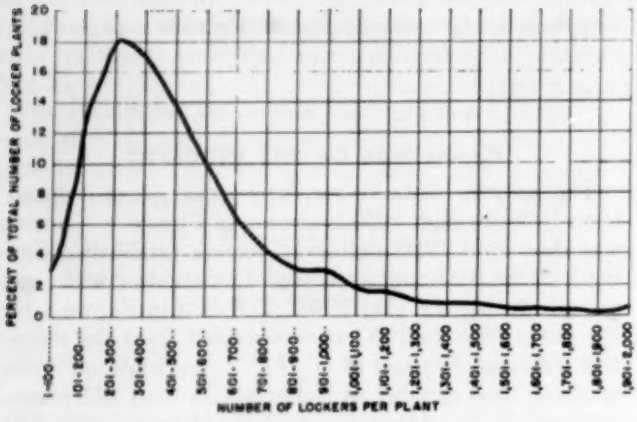

FIG. 2. Number of individual lockers per frozen food locker plant.

This survey showed that a large number of the locker plants have their own slaughtering facilities, and that it takes about an hour for the slaughtered animal to arrive in carcass form at the chill room. This is in contrast with animals not slaughtered on the premises which require from 1 to 24 hours to arrive at the chill room. Prior to sticking, the animals are usually shot or stunned. It takes from ½ to 1 man-hour to slaughter

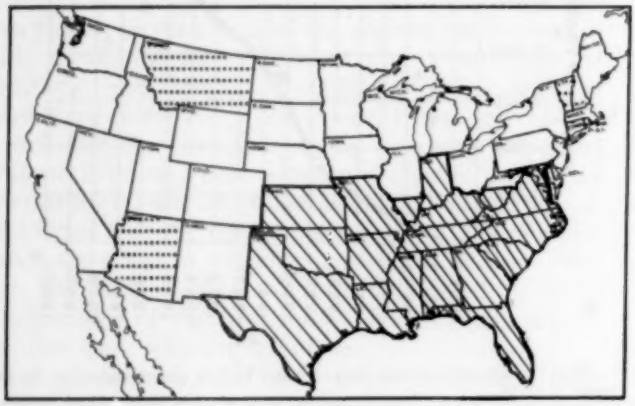

FIG. 3. Dry curing and brine curing sections of the country. Striped areas indicate predominant use of dry cure, dotted areas use of brine cure and unmarked areas use of both dry and brine curing.

and dress one beef. To skin a hog requires from ¼ to ½ man-hour per hog. Air temperature during slaughtering and dressing ranged from 4.5 to 27° C. (40 to 80° F.). Pork is kept in the chill or aging room usually from 1 to 3 days, beef from 5 to 7 days, and veal and lamb from 2 to 5 days. The chill and aging rooms are kept at 1 to 3.5° C. (34 to 38° F.), and in almost one-half of the locker plants, these rooms are equipped with ultra violet lights which are in operation continuously.

MEAT FREEZING

Air-blast freezing is used in 35% of the plants, plate-freezing in 30%, still-air type of freezing in 23%, and a combination of these methods of freezing in 12%. Generally, freezing temperatures of —23.5 to —29° C. (—10 to —20° F.) are used, with meat kept in the freezers for 12 to 24 hours. Beef cuts, which generally are boned before freezing, include rib, neck, shank, and rump; pork cuts, occasionally boned, include shoulder, ham, head, and flank. Ground pork is generally frozen without addition of salt as condiment. During freezing and subsequent storage, meat is protected by a wrapper of waxed locker paper, cellophane, aluminum foil, laminated paper, or a combination of two of these materials. Table 1, used with the permission of J. D. Winter *(2)*

TABLE 1

Sheet materials for wrapping frozen foods [c]

Type of Wrapping Used	Number of Plants	Percentage [d] of Plants
Waxed locker paper	7,008	65.4
Cellophane	2,250	21.0
Laminated glassine	2,111	19.7
Aluminum foil	1,714	16.0
Double-wound cellophane	1,211	11.3
Laminated cellophane	568	5.3
Thermoplastic wax dip	557	5.2
Laminated aluminum foil	396	3.7
Pliofilm	396	3.7

[c] From a paper by J. D. Winter *(2)*.
[d] Based on a total number of 10,715 locker plants.

shows the various types of wrapping materials and the extent to which they are used. Some plants use more than one type of material. Meat is single-wrapped by 43% of the operators, double-wrapped by 47%, and both single or double wrapped by 10%. The butcher wrap is used in 67% of the plants, the drugstore wrap in 23%, both butcher wrap and drugstore wrap in 5%, and miscellaneous methods of wrapping are used in 5%. Heat sealing is used only in 10% of the plants. Usual storage temperature is —18 to —17° C. (0 to 2° F.), with forced air circulation in 46% of the plants. Fresh and cured pork, fresh lamb, and cured beef remain in freezer storage for an average of 3 to 6 months, fresh beef and fresh veal for 6 to 8 months, and occasionally all types of meat are stored for 12 months.

MEAT CURING

Dry Curing. The length of time between the cutting of meat and its being placed in cure is from 24 to 48 hours. During this interval the meat temperature is from 1 to 3.5° C. (34 to 38° F.). Meat intended for curing is pumped by 79% of the operators; 67% pump pork hams and shoulders, and 12% pump beef rounds and dried beef. Commercially prepared curing mixtures are used in about 95% of the plants, both for pumping and subsequent dry curing. A number of plants use other curing mixtures, in addition to using commercial mixtures. The meat is pumped to 10% increase of its net weight, usually by the "stitch" method, although 13% of the operators use arterial pumping and 31% pump by both methods.

Usually from 4 to 8 pounds of dry mixture is used per 100 pounds of meat cured, with 70% of the operators applying all of the mixture at one time. In curing beef, from 1 to 10 pounds of dry mixture per 100 pounds of meat is used. The curing temperatures are from 2 to 4.5° (36 to 40° F.) and the meat is cured for 2 days per pound by 51% of the curers, for 1 day per pound by 18%, for 3 days per pound by 9%, with 22% using shorter or longer curing periods. During cure, the meat is usually piled and the extracted liquid permitted to drain away.

Approximately 10% of the plants prepare their own curing mixtures, using various proportions of salt, sugar, and saltpeter. Half of these plants also use commercial curing mixtures and are included in the 95% mentioned above as using commercial curing mixtures.

Brine Curing. The time elapsing between cutting of meat and placing it in cure is from 1 to 48 hours, most operators requiring 12 to 24 hours. Meat curing temperatures are 0 to 4.5° C. (32 to 40° F.), and during cure the meat is "piled" by 53% of the curers. Ninety-one percent pump the meat prior to brine curing, including such cuts as pork hams, shoulders, loins, bacons, beef rounds, brisket, and dried beef. A commercially prepared curing mixture is used in 85% of the locker plants, with 36% preparing their own mixtures. Here, again, many locker plants use other curing mixtures in addition to commercial mixtures. A typical locker plant mixture consists of salt, 10 pounds; cane sugar, 2 pounds; saltpeter, 3 ounces; and 23 quarts of water. During pumping the meat temperature is kept at 1 to 4.5° C. (34 to 40° F.), and the pumping mixture at 2 to 4.5° C. (36 to 40° F.). The net weight of meat is increased 10% by either stitch or artery pumping by 68% of the operators. (Stitch pumping 52%, artery 17%, both methods 31%).

Cover pickle is made in 68% of the plants from commercially prepared mixes, and is made in 40% of the locker plants from mixtures specific to a particular plant. Some locker plants use more than one type of curing mixture. A typical mixture of this sort would contain 7.5 pounds of salt, 3 pounds of cane sugar, 1.5 ounces of saltpeter, and 24 quarts of water. Curing is carried out at 3.5 to 4.5° C. (38 to 40° F.), with 61% of the operators overhauling the meat during cure. The meat is cured from 1 to 2 days per pound of meat.

Smoking and Storage. After the meat is cured it is either washed or soaked to remove excess surface curing materials. Hams are soaked from 1 to 8 hours, bacons from 1 to 4 hours, and dried beef from 1 to 7 hours. After soaking the meat is dried from 6 to 12 hours at 21 to 49° C. (70 to 120° F.), then smoked with ordinary wood smoke. Hams are smoked from 8 to 24 hours at smokehouse temperatures ranging from 49 to 65.5° C. (120 to 150° F.), bacons 3 to 12 hours at 49 to 60° C. (120 to 140° F.), shoulders 11 to 24 hours at 49 to 65.5° C. (120 to 150° F.), and beef 4 to 20 hours at 49 to 68.5° C. (120 to 155° F.). Smokehouse temperatures are controllable in 83% of the plants. Hams and shoulders were considered most susceptible to spoilage, although 65% of the operators reported no spoilage, 25% reported 1% spoilage, 3% reported 2% spoilage, and 3% reported 3% spoilage. Pumped cuts were considered less susceptible to spoilage than unpumped ones.

Cured meat was stored by 97% of this group of processors. In preparation for storage the cured meat was wrapped in locker paper, waxed paper, cellophane, laminated paper, or foil. Approximately 80% of the locker plant operators in this group stored most of their cured meat at locker room temperature, the remainder stored it at chill room temperature or at ordinary room temperature. Bacon is sliced before storage by 37% of the curers (some slice 90% of the cured bacon, some 50%, others slice only 6%).

SUMMARY

Results of questionnaires sent to 11,074 frozen food locker plants, 5,596 of which responded, showed that 93% freeze meat, 73% store cured meat, 25% brine cure, 40% dry cure and 33% operate their own slaughter house.

The largest numbers of plants are found in Iowa, Washington, Minnesota, and Wisconsin. The locker plants with the greatest number of lockers per plant are located in West Virginia, Pennsylvania, Oregon, and Maryland.

The frozen food locker plant industry, beginning in 1908 grew from about 50 plants in 1920 to 11,074 in 1950.

Typical freezing operations include wrapping the meat in protective waxed paper, foil, cellophane, or laminated paper, then freezing at —23.5° C. (—10° F.), for 24 hours, and subsequently storing at —17° C. (0° F.), for 3 to 12 months.

Dry curing by typical locker plant methods is carried out by pumping the meat to an increase of 10% in net weight with a commercial curing mixture, followed by dry curing for 1 to 2 days, using 10 pounds of dry mix per 100 pounds of meat.

Brine curing is carried out by pumping to an increase of 10% in net weight with a commercial curing mixture, followed by brine curing for 1 to 2 days per pound again using a commercial curing mixture.

After curing, the meat is washed, smoked for 2 to 3 days, wrapped in various packaging materials for protection, and stored from 3 to 12 months at freezer temperature, chill room temperature, or ordinary room temperature.

Temperature of the meat, curing and pumping brine, and curing rooms are in the range of 1 to 4.5° C. (34 to 40° F.).

About one-half of the locker plants use ultra-violet lights in their chill and aging rooms.

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Objective Measurement of Changes in Beef During Heat Processing

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(Manuscript received March 26, 1951)

Shoulder clod cuts of beef have been used as experimental units to demonstrate the extent of changes in tenderness, drained juice, moisture content, and pH during heat processing. Processes ranged from 5 minutes at 124° C. (255° F.) to 120 minutes at 107° C. (225° F.). The rate of change in the factors measured was proportional to the processing temperature. The sterilization values of the processes were found to be fairly high before the tenderness of the meat reached a maximum.

Commercially sterile beef in hermetically sealed cans may be prepared in a variety of ways. Canned beef, beef and gravy, and many other combinations of beef with other food products are familiar canned foods.

Experience has indicated that beef which is canned without the addition of other foods is not generally as acceptable as beef-containing combinations. This condition is a result of the changes which take place in beef during the heat process and, subsequently, during storage. During processing, changes occur in color, texture, juiciness, and flavor. The color changes from red to brown or grey. The texture usually becomes less firm due to the formation of gelatin from collagen. This change allows the meat fibers to separate to a degree depending on the time and temperature of the process used. The end result is a product in which the individual meat fibers retain considerable strength while the amount of collagen which binds the fibers together is diminished until the fibers may be separated easily. This condition may be described as "stringiness" and is not considered desirable in a canned meat product.

In addition to the development of stringiness, moisture is released from the meat during processing. The meat is then cooked in its own juice and acquires a "boiled beef" flavor which appears to be less acceptable than the flavors which result from roasting similar meat.

The present study has as its objective the description of changes in the tenderness, moisture content, amount of drained juice, and pH of meat during heat processing of canner and cutter grade beef shoulder clods using three processing temperatures in combination with a series of equally spaced processing times.

[a] Journal Paper No. J-1920 of the Iowa Agricultural Experiment Station, Ames, Iowa.

[b] Project No. 1123. This paper reports research undertaken in cooperation with the Quartermaster Food and Container Institute for the Armed Forces, and has been assigned Number 331 in the series of papers approved for publication. The views or conclusions contained in this report are those of the authors. They are not to be construed as necessarily reflecting the views or indorsement of the Department of the Army.

Objective tests for shear force, moisture, drained juice, and pH were used to describe the changes which occurred during processing.

Lowe and Stewart *(12)* have suggested limitations of objective tests and have indicated that these evaluations are at best only attempts to obtain impersonal measurements of palatability factors usually determined by subjective means.

Many investigators have employed the Warner-Bratzler shear apparatus to determine the tenderness of meat. Among the investigators who have found high correlation of shearing tests and panel scores are Hankins and Hiner *(11)*, Lowe and Stewart *(12)*, and Ramsbottom and Strandine *(14)*. These workers used 1-inch cylindrical samples of meat (cut parallel to the fibers). Bratzler *(7)* has stated that recently work has been done using ½-inch cylinders, apparently with no loss in accuracy of results.

Determinations of juiciness have been obtained with various types of presses. Gaddis, Hankins, and Hiner *(8)* in reviewing the results of these tests presented information which indicated that the correlations obtained between press fluid and juiciness scores were not conclusive.

Hall *(10)* has indicated that the sum of the moisture and fat content of muscles is very nearly constant. He also suggested that the muscles containing large amounts of fat tended to yield less press fluid because the fat was more difficult to press from muscles than the moisture it had replaced. Brady *(6)* in reviewing chemical and physical tests which have been applied to meat, suggested that an analysis of total moisture by the Association of the Official Agricultural Chemists vacuum oven method could be used as an index to the changes, or differences, in juiciness of meat.

Baker *(3)* reported that the most important changes occurring in meat during cooking were loss of weight (chiefly as moisture) and loss of solubility of proteins due to heat coagulation.

Theis and Jacoby *(15)* reported that the iso-electric point of heat denatured collagen was more alkaline than that of native collagen. Okuda *(13)* and Green *(9)* have both reported that the pH of heat-processed canned beef was higher than that of fresh beef.

EXPERIMENTAL PROCEDURE

Selection of Grade and Cut of Beef. Most studies of changes in meat due to storage time, storage temperature, and cooking which have been made in the past have indicated that rigid control of sampling procedures should be maintained. Control of sampling has been maintained in many investigations through use of paired muscles from the same animal. Special attention has been given to the size, age, previous diet, and general condi-

tioning of the animals used as sources of meat for study. These studies were mainly concerned with the high quality cuts of meat which are ordinarily used for roasting and frying.

When beef is canned commercially, it is common practice to use all of the available cuts from a carcass without regard for their individual characteristics. For this reason the experimental designs employed in this investigation were based on cuts of meat instead of on individual muscles.

The beef shoulder clod of canner and cutter grade was chosen as one of several representative cuts which could have been employed. In view of the possible influence on the results of the size and shape of the pieces used, approximately inch cubes were used throughout. This procedure had the advantage of providing a more homogeneous sample of individual cuts than would have been possible if larger pieces had been used.

Arrangements were made with a commercial packer to have fresh meat delivered as needed during the course of this experiment to reduce the variation in the meat due to storage time. Storage time after the meat arrived from the packer was limited to a maximum of 5 days. Upon receipt from the packing plant the meat was wrapped in heavy waxed paper and stored in a refrigerator at a temperature of 0° C. (32° F.).

Three processing temperatures, 107, 116, and 124° C. (225, 240, and 255° F.), were employed. For each processing temperature a 4 x 9 randomized complete block design was used. Numbers were assigned to the process times which were arbitrarily chosen but equally spaced within a temperature category. For each clod the numbers were chosen at random to establish the order of processing the treatments within that clod. Each clod represented a replicate consisting of 9 treatments including a control which received no thermal processing. The times and the temperatures used are shown in Table 1.

TABLE 1

Time—temperature combinations used in processing beef shoulder clods

Temperature, ° F.	Times in minutes							
225	15	30	45	60	75	90	105	120
240	10	20	30	40	50	60	70	80
255	5	10	15	20	25	30	35	40

In preparing the meat for canning the clods were removed from the refrigerator [0° C. (32° F.)] and cut into cubes (of about 1-1½ inch on a side) and thoroughly mixed in a kettle to randomize the variation among pieces. After mixing, 470 g. of meat were packed into each of the nine No. 2 cans, the cans were vacuum sealed, and stored in a refrigerator at 4.5° C. (40° F.) for a period of about 16 hours before processing was begun. When processing was begun on a given replicate it was completed in as short a time as possible to minimize the differences in storage times among the samples in that replicate. The time between treatments within a replicate was usually about 15 minutes. (Ten minutes for cooling the cans from the preceding treatment and five minutes of venting the retort before processing temperature was reached on the following treatment).

Steam was allowed to pass through the loaded retort for 5 minutes with all vents wide open to exhaust the air and moisture. The vents were then closed and the retort allowed to come up to processing pressure. The process time was started when the retort reached the required processing temperature (about 30-40 seconds after closing the vents) and continued until the steam was shut off and cooling was begun. Cooling was accomplished with cold water at approximately 10-15.6° C. (50-60° F.).

Temperatures were measured using thermocouples located at the center of each can and were recorded by means of an eight point automatic recording potentiometer.

In the determination of shear force, cylinders were cut from the drained meat so that the direction of the fibers in the meat was parallel to the longitudinal axis of the cylinder obtained. All shear force measurements in this study were made on ½-inch cylinders. It was found that when using a ½-inch cork borer, very slight pressure was needed to cut the cylinders if the cork borer was kept sharp and a rotating or boring action was used. After cutting all the cylinders possible from the meat in the sample, 10 were selected at random from each of 4 replicates for measurement of shear force with the Warner-Bratzler Shearing machine. In most cases only 10 or 12 cylinders could be cut from a given can of meat and therefore very few of the potential number of cylinders from the can were discarded.

In the determination of the weight of drained juice, the can, contents, and a No. 8 U. S. Standard Sieve were weighed together on a torsion balance and the weight was recorded to the nearest gram. The can was then inverted on the sieve and the juice was allowed to drain for three minutes. After draining, the can, contents, and sieve were again weighed and the loss in weight was recorded as the weight of drained juice.

The official method of determination of moisture (vacuum oven) of the A. O. A. C. *(2)* was used. Samples for the determination of moisture were taken from the meat remaining after shear force determinations had been made. These samples were ground 3 times in a Hobart Food Chopper equipped with a ⅛-inch plate. Approximately 6 g. of ground meat were weighed to ± 0.01 g. on a torsion balance in aluminum drying dishes 7.5 cm. in diameter and 2.5 cm. deep. Drying was continued for 6 hours at 95-100° C. (203-212° F.) at a pressure of less than 100 mm. in a vacuum oven. Two determinations were made for each can of meat.

After the drained juice determination was made, a 25-ml. sample of the juice was used for measurement of pH. All pH determinations were made with a Leeds Northrup glass electrode pH meter standardized with pH 7.00 buffer solution.

In calculating the lethality of the processes used, the center temperatures of the 8 cans receiving the same processing treatment were averaged and the F_0 value of that process calculated by General Method *(5)*. The lethalities used were derived by assuming F equal to 1 and z equal to 18 for the thermal death time curve.

DISCUSSION

In the experimental plan used in this study, three equally spaced processing temperatures were applied. At each temperature a series of nine equally spaced times were used for processing. This arrangement was used to allow for treatment of the data by means of orthogonal polynomials *(1)* for fitting curves. This method is especially valuable in studies involving time series where the data are equally spaced and was used in this investigation to describe graphically the changes in shear force, drained juice, moisture content, and pH during processing. Under these conditions each degree of curvature and the deviations from it may be calculated independently of all others. In this study, the relationships between processing times and the effect being measured approximated second degree curves at each processing temperature.

The measurements of changes in shear force shown in Figure 1 indicate that the tenderness of the beef shoulder clods used in this work increased very quickly during the earlier stages of the process, with the rate of change inversely proportional to the processing time. The rate of change of shear force is also directly proportional to the processing temperature. The times required to reach a minimum shear force at each processing temperature appear to be approximately linearly related to the temperature employed. The levels of shear force at which minima occur, however, are not linearly related. The minimum shear force for 116° C. (240° F.) is lower than those for 107° C. (225° F.) and 124° C. (255° F.).

The drained juice and moisture curves (Figures 2 and 3) are, in a sense, complementary in that moisture lost from the meat during processing accumulates in the

can as juice. The drained juice is composed mainly of fat and water and these two components have not been differentiated in the present discussion.

The processing time-temperature relationships for drained juice and for moisture retained in the meat resemble closely the shear force curves. In both cases,

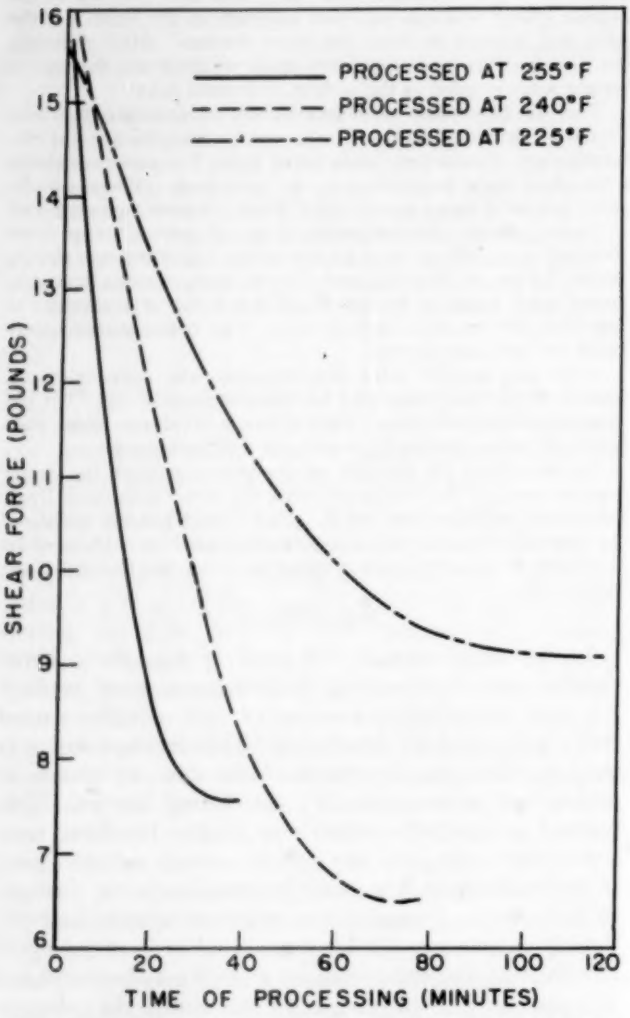

FIG. 1. Changes in tenderness (shear force) with processing time at processing temperatures of 107° C. (225° F.), 116° C. (240° F.) and 124° C. (255° F.).

the rate of change is directly proportional to the processing temperature. The maximum time values for drained juice and the minimum time values for moisture are approximately linearly related to the processing temperature.

The pH curves shown in Figure 4 fail to indicate the clear-cut effects of temperature which are found in the shear force, drained juice, and moisture curves. The times required to reach a maximum, however, are approximately linearly related.

The analyses of variance for shear force, drained juice, moisture content, and pH are shown in Table 2 to illustrate the comparative magnitudes of variations arising from replicates (clods), treatments (processing times), and individual sets of determinations in each can. In all cases except one the replicates contributed considerably to the variability of the results. Inspection of the table

TABLE 2

Analyses of variance of shear force, drained juice, moisture content, and pH data

	Degrees of freedom	Variance (mean square)		
		Processing temperatures		
		225° F.	240° F.	255° F.
Shear force				
Source of variation				
Replicates	3	49.35*	20.85	159.17**
Treatments	8	245.30**	640.44**	387.65**
R x T (error)	24	10.48	27.15**	27.74**
Determinations in a can	324	11.32	10.93	13.82
Total	359			
Drained juice				
Replicates	7	230.71**	248.57*	204.75*
Treatments	8	20576.12**	19514.03*	19246.36*
R x T (error)	56	43.50	87.85	38.23
Total	71			
Moisture content				
Replicates	7	15.79**	65.66**	25.19*
Treatments	8	170.48**	202.75**	178.08*
R x T (error)	56	2.10	2.56	2.82
Determinations in a can	72	0.86	0.89	0.76
Total	143			
pH of juice				
Replicates	7	0.043**	0.055**	0.078**
Treatments	8	0.251**	0.235**	0.128**
R x T (error)	56	0.0087	0.013	0.009
Total	71			

*Significant at 5% level. **Significant at 1% level.

indicates, however, that the variations which may be ascribed to the influence of processing times (treatments) were far greater in every case than that due to replication. The use of individual beef shoulder clods

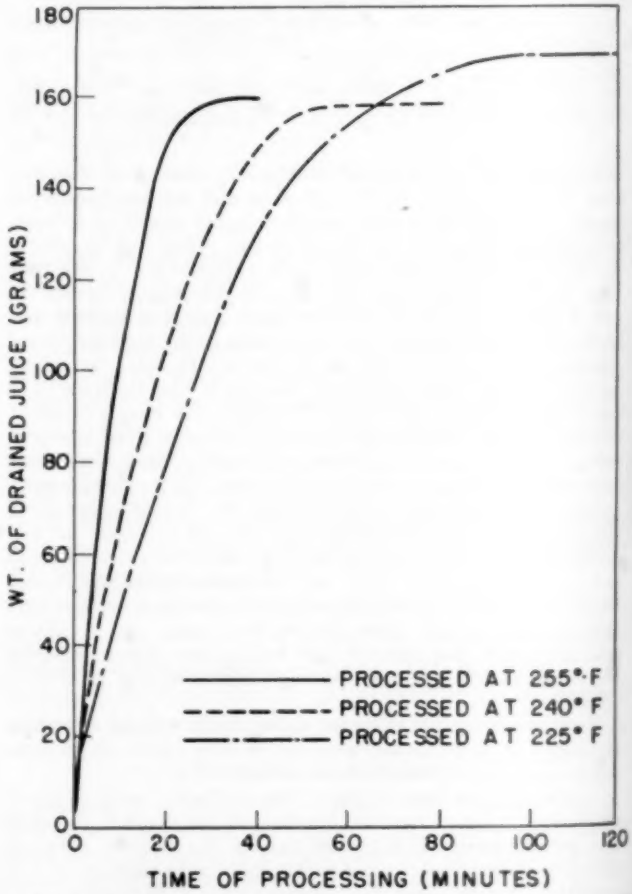

FIG. 2. Changes in drained juice with processing time at processing temperatures of 107° C. (225° F.), 116° C. (240° F.) and 124° C. (255° F.).

TABLE 3

Mean F_o values for twenty-four processes at 107, 116, and 124° C. (225, 240, and 255° F.)

Process temperature 225° F.		Process temperature 240° F.		Process temperature 255° F.	
Process time (minutes)	Mean F_o[a]	Process time (minutes)	Mean F_o[a]	Process time (minutes)	Mean F_o[a]
15	<0.007	10	<0.005	5	<0.00008
30	0.007	20	<0.005	10	<0.00008
45	0.094	30	0.06	15	<0.00008
60	0.606	40	1.40	20	0.004
75	1.268	50	5.06	25	2.006
90	1.733	60	10.91	30	4.098
105	2.313	70	13.86	35	8.016
120	2.504	80	18.12	40	28.05

[a] Each lethality value above was calculated from the average heat penetration curve of 8 determinations.

as replicates suggests that the effects of varying time and temperature of processing may be demonstrated using these cuts as experimental units.

Comparison of the F_o value of the processes shown in Table 3 indicates clearly that the maximum (or minimum) values of shear force, drained juice, moisture, and pH (Table 4) were reached only after the sterilization value of the process had attained fairly high values. While these data are only approximations, they suggest that high temperature, short time processes may hold some promise of improvement in the quality of canned beef if, by this means, sterilization may be accomplished before appreciable changes have taken place especially in tenderness and in the production of free juice. Additional investigations are being planned which will include several cuts of meat and additional ranges of times and temperatures of processing in an effort to provide a more rigorous measure of the changes which take place during processing.

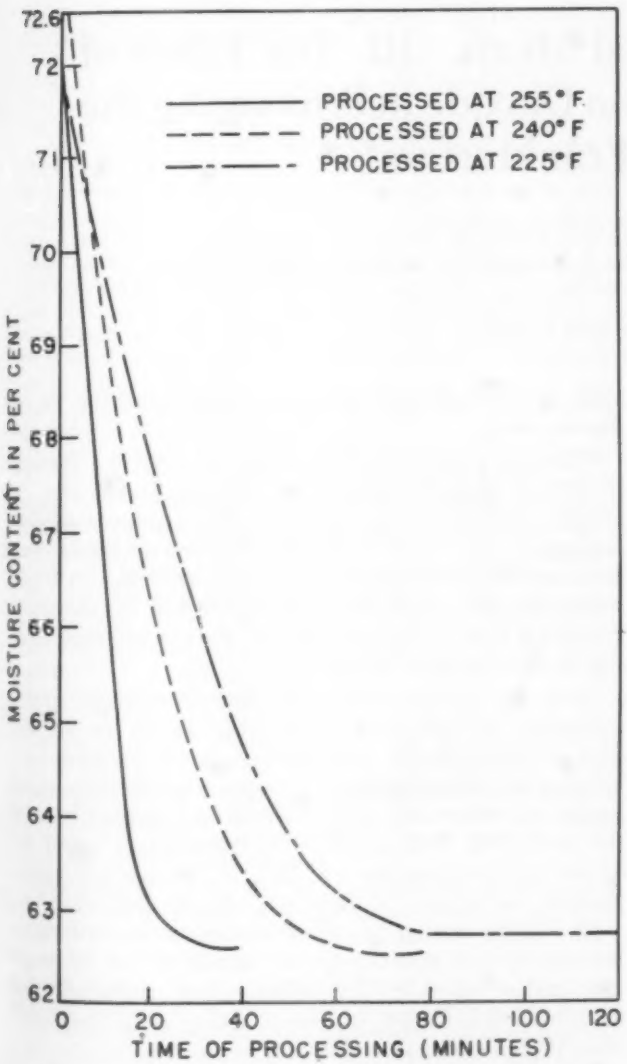

FIG. 3. Changes in moisture content with processing time at processing temperature of 107° C. (225° F.), 116° C. (240° F.) and 124° C. (255° F.).

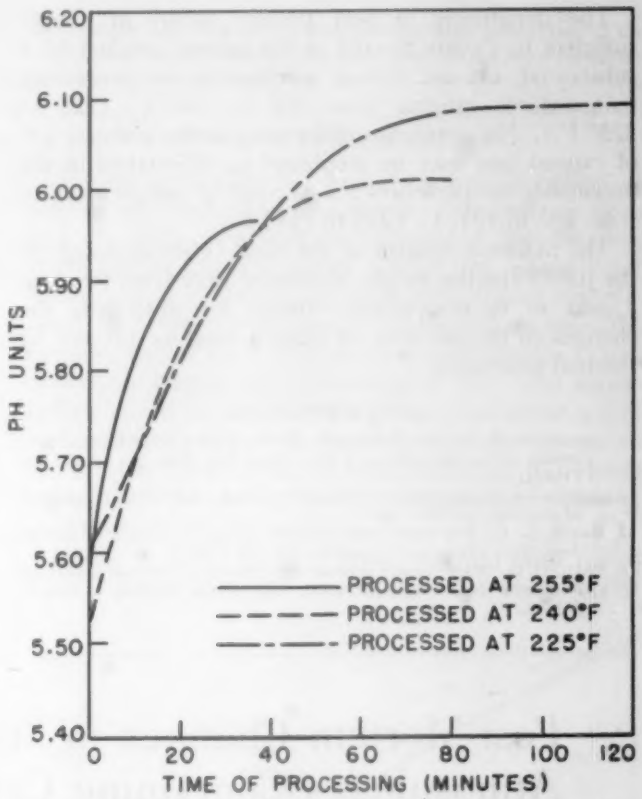

FIG. 4. Changes in pH with processing time at processing temperatures of 107° C. (225° F.), 116° C. (240° F.) and 124° C. (255° F.).

TABLE 4

Approximate minimum or maximum values in minutes of processing times for shear force, drained juice, moisture content, and pH

	Processing temperature 255° F.	240° F.	225° F.
	Time (Min.)		
Shear force (minimum)	36	70	100
Drained juice (maximum)	34	60	98
Moisture content (minimum)	36	68	88
pH (maximum)	40	68	120

SUMMARY

The tenderness of canned beef approached a maximum at a stage in the processing after sterilization values were fairly high. The rate of increase in tenderness of canned beef measured by shear force, the quantity of drained juice, and the moisture content of the meat are direct functions of processing temperature within the range of 107 to 124° C. (225 to 255° F.).

The denaturing of beef protein occurs at a rate sufficient to elevate the pH of the canned product by a substantial amount during sterilization at processing temperatures ranging from 107 to 124° C. (225 to 255° F.). No significant differences in the ultimate pH of canned beef may be attributed to differences in the processing temperatures for a range of temperature of from 107 to 124° C. (225 to 255° F.).

The moisture content of the meat (after draining off the juice) and the weight of drained juice from the meat appear to be comparable criteria for describing the changes in the juiciness of canned meat as affected by thermal processing.

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Post-Mortem Changes in Stored Meats. III. The Effect of Atmospheres Containing Carbon Dioxide in Prolonging the Storage Life of Frankfurters[a]

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(Manuscript received April 5, 1951)

Experiments show that carbon dioxide improves the storage life of frankfurters without exerting any detrimental effects. The effects of various concentrations of carbon dioxide at different temperatures, relative humidities, and for different lengths of time on the storage life of frankfurters are discussed. Changes in appearance due to microbial growth generally were noted before definite alteration in flavor could be observed.

In Part II of this series of papers *(5)*, carbon dioxide was reported to be an effective agent for extending the keeping time of cut-up chicken. An increase in carbon dioxide concentration or a reduction in storage temperature markedly improved the effectiveness of the gas. In the absence of oxygen, the types of bacteria developing on chicken were much less inhibited by carbon dioxide than were the typical aerobic slime formers. Concentrations of the gas above approximately 25% were considered unsatisfactory because of the resulting rapid discoloration.

Different results would be expected from the storage in carbon dioxide atmospheres of the frankfurter, a cured, comminuted meat product, than from the similar storage of chicken, a fresh meat. The frankfurter contains a different pigment from that occurring in fresh meat; the salt concentration is higher and the moisture content is lower; the predominant flora developing during storage is quite different.

Although considerable information is available in the literature on the storage of fresh meats in carbon dioxide atmospheres, very little has been reported concerning the effectiveness of the gas in preserving cured meats. Killeffer *(3)* observed that, at a temperature of 4.4 to 7.2° C. (40 to 45° F.), frankfurters could be stored two to three times as long in commercial carbon dioxide as in air. Callow *(1)* found that at 5° C. (41° F.) the storage life of mild-cured, unsmoked bacon was more than doubled by an atmosphere of commercial carbon dioxide. In addition, the appearance of bacon stored in the gas was described as being "brighter" than that of bacon stored in air.

The influence of relative humidity on growth of microorganisms on meat surfaces needs clarification.

[a] Appreciation is expressed to the Pure Carbonic Company, a division of Air Reduction Co., Inc., N. Y., N. Y. for support, in part, of this research.

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[c] Journal Paper No. J-1929 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 1161.

The general opinion among workers in the meat industry seems to be that some reduction in humidity facilitates preservation of all types of meat. However, there is evidence in the literature that any feasible reduction in relative humidity has little effect in delaying microbial growth on small pieces of meat.

From osmotic pressure measurements, Walter *(9)* calculated minimum relative humidities for growth of 96% for bacteria and 85% for molds. Scott *(7)* pointed out that the relative humidity of the storage atmosphere does not determine the humidity of the environment surrounding the microorganisms at the meat surface unless an equilibrium has been established between moisture in the meat and moisture in the atmosphere. Diffusion of water from the interior of meat will maintain a higher humidity at the surface than will be indicated by the moisture content of the surrounding air.

According to Haines and Smith *(2)*, bacterial growth on small pieces of beef stored at 0° C. (32° F.) was little slower at 70% relative humidity than at 100% even though excessive weight losses occurred at the lower humidity. Yesair *(10)* stated that growth of molds on sausage in drying rooms could not be prevented by any practicable combination of temperature, humidity, and air circulation.

EXPERIMENTAL

Skinless, uncolored, all meat frankfurters [4] were received from a nearby packing house on the day after manufacture, and were used in the experiments on the day following receipt. Refrigeration was continuous from the time of production to the time of use. Commercial carbon dioxide secured in the liquid form in cylinders was used throughout this study.

Frankfurters were placed on end in sterile two-quart Mason-type jars containing small amounts of distilled water in order to maintain relattive humidity near 100%. After the desired amounts of carbon dioxide had been added, jars were sealed and placed in refrigerators. At intervals based upon knowledge of expected keeping times, frankfurters were removed for organoleptic and bacteriological tests.

Carbon dioxide atmospheres were obtained in the jars by: (1), evacuation and subsequent replacement with measured amounts of carbon dioxide and air; (2), continuous passage of a controlled carbon dioxide-air mixture; (3), rapid displacement of the jar atmosphere by a controlled carbon dioxide-air mixture. The third method was the one generally employed. This displacement procedure was repeated as often as necessary during storage to prevent excessive variations in carbon dioxide level and also was employed after a jar had been opened for any reason. Further information on apparatus and methods can be found in previous publications *(5, 6)*.

In the relative humidity study, weighed frankfurters were placed on perforated porcelain plates in 160 mm. diameter desiccators. Each of 5 desiccators contained 200 ml. of sulfuric acid solution of the concentrations needed to provide relative humidities of 75, 80, 85, 90, and 95%. A sixth desiccator held 200 ml. of distilled water. Desiccators were opened periodically for weighings and microbial counts.

Measurement of storage life generally was based on undesirable changes in external appearance caused by microbial activity. A sample was considered spoiled when surface slimes or greenish discolorations were first noted or when discrete colonies attained an approximate diameter of 1 mm. Off-odor was not a sensitive method of determining end points due to the strong natural odor of the samples and to the many different types of spoilage encountered. Under some conditions of storage, neither odor nor appearance gave reliable indications of the condition of stored samples. In such cases flavor may constitute the only satisfactory criterion.

[4] Kindly furnished by the Rath Packing Company, Waterloo, Iowa.

RESULTS AND DISCUSSION

Storage of frankfurters in carbon dioxide caused no deleterious effects on flavor or color; concentrations as high as 96% produced no noticeable discoloration. High carbon dioxide levels tended to reduce color fading which sometimes occurred when air or low carbon dioxide levels were used in storage. Color retention probably can be ascribed to exclusion of oxygen as discussed by Urbain and Ramsbottom *(8)*. The frankfurters stored in jars containing high concentrations of carbon dioxide often developed a wrinkled, shrunken appearance. These changes were attributed to reduced pressures in the storage jars resulting from solution of carbon dioxide in the samples.

Figure 1 shows keeping times obtained with frankfurters stored with different carbon dioxide levels at

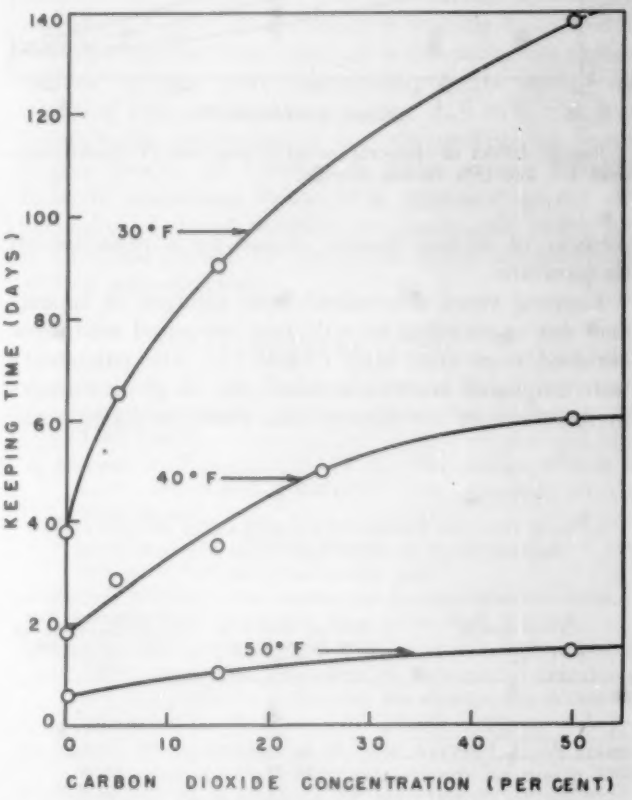

FIG. 1. Effect of carbon dioxide concentration on storage life of frankfurters at 30°, at 40°, and at 50° F. (4.4°, 7.2° and 10° C.).

several temperatures. These times were determined from visual manifestations of microbial growth and were not necessarily the same as keeping times based on palatability tests. An increase in carbon dioxide concentration up to levels of 50% gave an improvement in storage life. Additions of carbon dioxide above 50% made little difference in the time at which microbial growth could be discerned. Curves tend to level off with increasing percentages of carbon dioxide.

End points with high carbon dioxide concentrations could not be defined with exactness. In general, storage life of samples stored in atmospheres containing 75% or 96% carbon dioxide was little longer than with 50% of the gas. Microbial growth was evidenced visually as a thin, watery slime which developed gradually. Greatly improved storage life resulted from the employment of a lower holding temperature.

Figure 2 demonstrates graphically the value of low storage temperature and points out the increased effectiveness of carbon dioxide caused by a reduction in temperature.

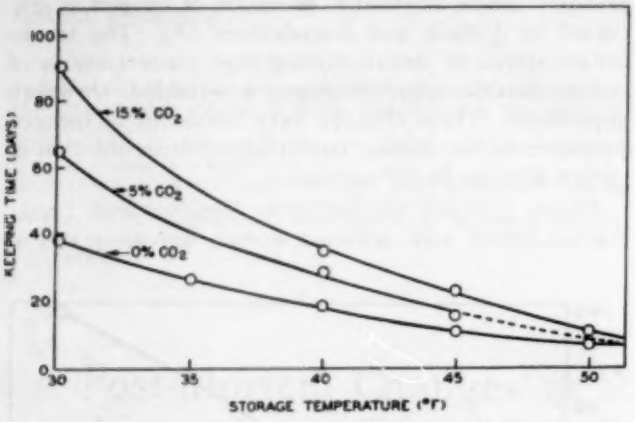

FIG. 2. Effect of temperature on storage life of frankfurters with 0, 5, and 15% carbon dioxide.

Keeping times determined from changes in appearance due to microbial growth were compared with those obtained from taste tests (Table 1). The palatability tests employed were indicative only of gross changes in flavor, since no attempt was made to judge small differences. Keeping times based on taste were somewhat longer than those determined by microbial growth, indicating that visible microbial development can be detected on frankfurters before any pronounced deterioration in flavor is noticed. An exception to this generalization was found in the case of samples stored at —1.1° C. (30° F.) with carbon dioxide levels of 15 and 50%. Here unpleasant flavors, presumably due to oxidative rancidity, were observed before any visible signs of microbial growth were apparent.

TABLE 1

Keeping time for frankfurters stored under various carbon dioxide levels as determined from microbiological and flavor end points *

Carbon dioxide level, %	Keeping time from gross flavor changes, days	Keeping time from visual observation of microbial growth, days
0	26	18
5	33	28
15	41	35
25	52, 72	50
50	ca. 72	ca. 60
75	72	ca. 60
96	72	ca. 60

* Storage temperature, 4.4° C. (40° F.).

It was noted that frankfurters stored with high carbon dioxide percentages eventually became very acid in taste. This observation suggested that measurement of hydrogen ion concentration might constitute a reliable method for determining storage life in such cases. With carbon dioxide levels below 25%, little change in pH was observed during storage; however, with atmospheres containing 50% or more of carbon dioxide, considerable reductions in pH (approximately one pH unit) were noted at approximately the same times that samples were considered spoiled by other methods.

According to Niven *(4)*, difficulties due to greenish discolorations on surfaces of sausages occur as epidemics. In the work here, a few batches of frankfurters were found to be much more susceptible to greening than the normal production. In Table 2 keeping times of normal samples are compared to those of samples which developed pronounced greening. When development of surface greening was a primary cause of spoilage, carbon dioxide was less effective although an increase in concentration still improved storage life. No greening occurred at —1.1° C. (30° F.) or with carbon dioxide levels of 75 and 96%.

TABLE 2

Effect of "greening" on the storage life of frankfurters at 4.4° C. (40° F.)

Carbon dioxide level, %	Average keeping time of normal samples, days	Average keeping time of samples susceptible to greening, days
0	18	18
15	35	25
25	50	40
50	ca. 60	50

The effect on storage life of a limited holding period in carbon dioxide followed by storage in air was studied in the case of frankfurters as had been done previously with chicken *(5)*. Table 3 shows the advantages gained by 5 or 10 day holding periods in carbon dioxide over those derived from continuous storage in air. Five percent carbon dioxide was of little value for this purpose; however, 25 or 96% was definitely beneficial.

TABLE 3

Effect of "part-time" storage with carbon dioxide

Storage atmosphere	Keeping time, days
Air continuously	10
5% CO_2 for 5 days, then air	10
5% CO_2 for 10 days, then air	11
5% CO_2 continuously	15
25% CO_2 for 5 days, then air	14
25% CO_2 for 10 days, then air	20
25% CO_2 continously	32
96% CO_2 for 5 days, then air	16
96% CO_2 for 10 days, then air	23
96% CO_2 continuously	ca. 40

The practicability of utilizing carbon dioxide for the preservation of frankfurters packaged in L.S.A.T. (semi-moisture proof) cellophane wraps was investigated. Samples which had been "soaked" in 96% carbon dioxide for 2 days were wrapped, sealed and stored

TABLE 4

Effect of relative humidity on changes of weight and proliferation of microorganisms for frankfurters stored at 4.4° C. (40° F.)

Initial relative humidity, %	Relative humidity at 31 days, %	Average weight change,[f] %	Numbers of bacteria and yeasts per frankfurter after				Time for mold growth, days
			9 days	15 days	20 days	31 days	
100	100	+0.7	3.0×10^3	1.3×10^4	9.5×10^6	2.3×10^9	15
95	97	−1.3	1.1×10^4	3.4×10^4	2.3×10^9	2.3×10^9	20
90	94	−4.0	1.7×10^3	2.7×10^5	5.0×10^6	1.5×10^7	15
85	92	−6.1	2.6×10^3	5.3×10^4	2.2×10^7	6.5×10^7	15
80	90	−7.2	3.5×10^3	2.2×10^5	2.7×10^7	1.4×10^7	15
75	90	−7.3	1.5×10^3	8.3×10^4	6.4×10^6	4.2×10^8	15

[f] Percent weight change after 15 days of storage.

in refrigerators. The carbon dioxide-treated samples showed evidence of spoilage at 4.4° C. (40° F.) and 7.2° C. (45° F.) at exactly the same time as did the controls. Apparently, the gas was lost through the wrap as rapidly as it diffused from the samples. A more nearly impermeable wrapping material than that commonly used at the present time with frankfurters will be necessary for packaging with carbon dioxide.

Since frankfurters have lower moisture and higher salt contents than does fresh meat, it seemed possible that reduced relative humidities might be employed successfully for prolonging storage life. In one experiment, changes in weight and the development of microorganisms were followed in the case of frankfurters stored at several humidities. The weight changes which were obtained after 15 days of storage at 4.4° C. (40° F.) are listed in Table 4. A serious shortcoming of this experiment becomes apparent when the relative humidities initially supplied in the desiccators are compared with relative humidities existing at the conclusion of the experiment (Table 4) as determined from specific gravity measurements on the acid solutions. Moisture from the frankfurters had diluted the sulfuric acid solutions; consequently the weight losses shown for the lower humidities were less than would have been the case had a constant humidity been maintained. Samples stored at relative humidities initially under 90% acquired a very undesirable appearance due to dehydration, and this effect was noted to some extent at 90%. Continued use of humidities below approximately 95% should result in prohibitive drying out of frankfurters.

Combined bacterial and yeast counts taken during storage and the times at which appreciable mold growth was observed also are given in Table 4. At the end of 20 days, considerable mold development was present on all samples. Numbers of bacteria and yeasts did not reach such high levels at the lower humidities and their growth undoubtedly would have been further restricted if humidities had remained constant. However, effective control of microorganisms on frankfurters by reduced humidity does not appear to be commercially feasible.

SUMMARY

Carbon dioxide improved the storage life of frankfurters without exerting any detrimental effects. The effectiveness of carbon dioxide increased with concentration up to a level of approximately 50%; further increases in concentration seemed to be of no help. Reduction of storage temperature lengthened keeping time of samples and also increased the effectiveness of carbon dioxide. Changes in appearance due to microbial growth generally were noted before definite alteration of flavor could be observed. However, use of temperatures near the freezing point of the meat along with carbon dioxide so restricted microbial development that oxidative rancidity seemed to be the limiting factor in storage. With carbon dioxide atmospheres of 50% and above, hydrogen ion concentration accurately reflected deterioration of samples. Subjection of frankfurters to atmospheres containing 25 or 96% carbon dioxide for periods of 5 or 10 days resulted in keeping times which, while inferior to those obtained with continuous carbon dioxide storage, were considerably better than those resulting from storage in air only. L.S.A.T. film was found to be unsatisfactory for gas packing of frankfurters due to its inability to retain carbon dioxide. Relative humidities below 95% produced severe dehydration of stored samples; no appreciable restriction of microbial growth by humidities in the neighborhood of 95% was observed.

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Fractional Blending Systems for Aging Alcoholic Beverages

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(Manuscript received March 13, 1951)

A theory of fractional blending in a solera-type system has been developed and applied to three simple cases. The practical importance of such a blending system and its further modifications are discussed.

An elaborate fractional blending procedure, called the *solera* system, is used in the production of sherry in Spain. The purpose of this blending system is to produce a beverage of characteristic type and uniform quality over a period of years. To set up a solera, wines of several ages but of the same general character are selected. A simple solera of four stages at the start might consist of 1 to 100 containers (called butts in Spain and containing about 130 gallons each) filled with 4-year-old wine, and approximately the same number filled with 3-year-old, 2-year-old, and 1-year-old wine. In the simplest case, equal amounts of wine are removed from the oldest containers once a year. The usual percentages withdrawn are 10 and 25. After the wine is drawn off, the containers from which the oldest wine has been removed are refilled to their original volume from the containers of the next youngest wine and so on. The youngest containers are filled with wine of the same type, usually of the current production.

Descriptions of the operation of the solera system in Spain are given by González-Gordon *(3)* and by Cruess *(2)*. As it is used for sherry, the producers are primarily interested in maintaining uniformity of type and quality. Brandy is aged by a similar system in Spain. Blending systems of the same general type are also used for Madeira and Marsala wines. In so far as we are aware, no systematic investigation of the average age of wines drawn from such systems has been published.

Fractional blending systems like the solera system are being introduced in California for sherry production. Systems of fractional blending of this type should be of interest to many producers of alcoholic beverages, such as port, muscatel, brandies, whiskies, and rums, all of which improve greatly by aging. Once such a fractional blending system has been set up it becomes more valuable with time, as some older wine—though a diminishing quantity—continues to be available from the oldest container. The average age of the wine in the oldest container increases rapidly at first, and later more slowly.

Those concerned with honesty in advertising and with law enforcement will wish to know how much wine of various ages there is in the product of such aging systems after given periods of time have elapsed. The results reported in this paper are for a drawing-off period of one year and for withdrawal rates of 10, 25, and 50%. Similar data with extended discussions and theoretical development, for this and other more complicated systems of fractional blending, are being published elsewhere *(1)*.

To illustrate the operation of a fractional blending system, let us start with 2 containers. Let p equal the proportion drawn off at the end of a year and q the proportion not drawn off. At the beginning, the second or bottom container in the system contains wine 1 year old, and the first or top container has wine zero years old. The operation is as indicated in Table 1. By a similar process, the exact proportion of wine of each age can be found for all containers for any system after any length of time. The results would be very cumbersome if presented in such detailed form. As a summary, we consider the average age of the contents of the last container during 50 years of operation for systems consisting of 4, 5, 6, 7, and 8 stages. These average ages are shown graphically in Figures 1 ($p = 0.25$), 2 ($p = 0.10$), and 3 ($p = 0.50$).

TABLE 1

Fractional Blending System Consisting of Two Barrels With a Drawing-off Period of One Year

End of period (years)	Barrel 1				Barrel 2			
	Before drawing		After drawing		Before drawing		After drawing	
	Age	Proportion	Age	Proportion	Age	Proportion	Age	Proportion
1	1	1	0 1	p q	2	1	1 2	p q
2	1 2	p q	0 1 2	p pq q^2	2 3	p q	1 2 3	p^2 2pq q^2
3	1 2 3	p pq q^2	0 1 2 3	p pq pq^2 q^3	2 3 4	p^2 2pq q^2	1 2 3 4	p^3 $2p^2q$ $3pq^2$ q^3
4	1 2 3 4	p pq pq^2 q^3	0 1 2 3 4	p pq pq^2 pq^3 q^4	2 3 4 5	p^2 $2p^2q$ $3pq^2$ q^3	1 2 3 4 5	p^2 $2p^2q$ $3p^2q^2$ $4pq^3$ q^4
5	1 2 3 4 5	p pq pq^2 pq^3 q^4	0 1 2 3 4 5	p pq pq^2 pq^3 pq^4 q^5	2 3 4 5 6	p^2 $2p^2q$ $3p^2q^2$ $4pq^3$ q^4	1 2 3 4 5 6	p^2 $2p^2q$ $3p^2q^2$ $4p^2q^3$ $5pq^4$ q^5

Figure 1 indicates that in a system of 4 stages, when 25% is removed once a year from the oldest container, the average age of its contents increases to a constant value of 15 years after about 30 years of operation, though the rate of increase is very slow after only 25 years. The 5-container system approaches a constant age of 19 years after a slightly longer period of time, the 6-container system gradually approaches a 23-year average, and the 7-container system 27 years. The average age of the contents of the oldest container of an

8-stage system is still increasing slowly after 50 years' operation and is 31 years of age.

Figure 2 shows that for a 10% drawing-off each year the average age of the contents of the oldest container in the 4-stage system is just beginning to approach a constant value of 35 years after 50 years of operation, while the oldest container of the 8-stage system has an average age of over 51 years and is still rapidly increasing.

It is obvious then that for a given number of years of operation, one may increase the average age in the last container by (a) increasing the number of stages in the system or (b) decreasing the percent drawn off each year.

If it is desired to reduce the average age of the final product below that for 25% drawing-off, a 50% drawing-off can be used. Such reduction may be desirable under commercial conditions. Figure 3 shows that with such a system the average age quickly becomes stable after relatively few years. There is little change after 14 years for a 4-stage system, 17 years for a 5-stage system, 20 years for a 6-stage system, 23 years for a 7-stage system, and 25 years for an 8-stage system. The oldest averages attained are 7.50, 9.50, 11.50, 13.50, and 15.50 respectively. These can be compared with 15.00, 19.00, 23.00, 27.00, and 31.00 for the 25% drawings-off presented in Figure 1, and 35.39, 41.45, 45.92, 49.01, and 51.17 for the 10% drawings-off of Figure 2.

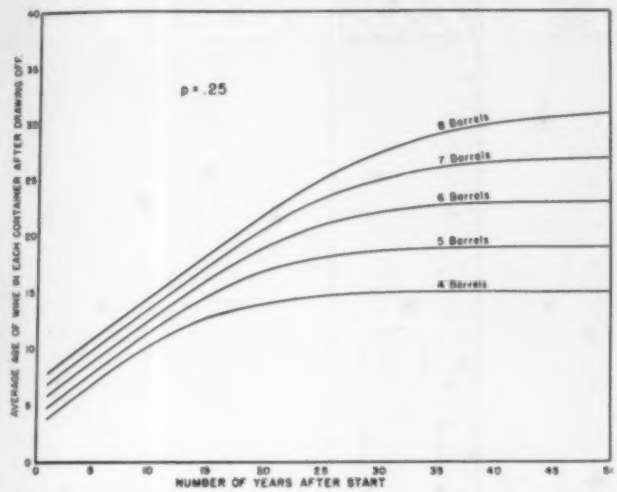

FIG. 1. Average age of the wine in the oldest container of 4, 5, 6, 7, and 8-barrel systems when 25% is removed once a year.

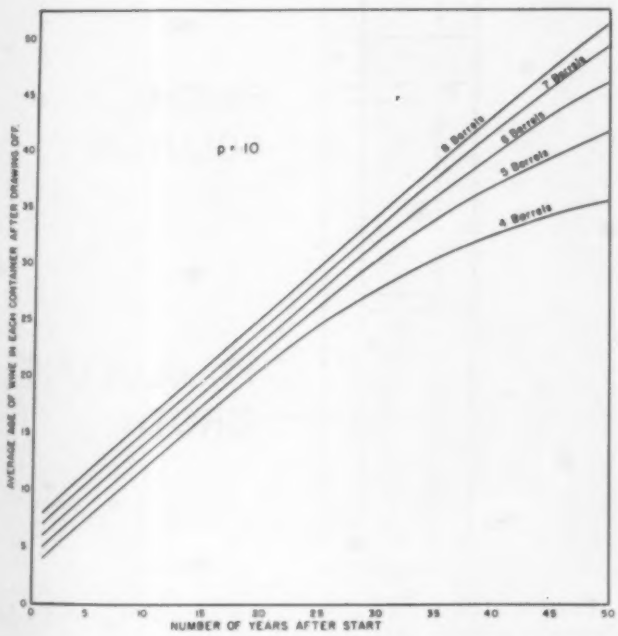

FIG. 2. Average age of the wine in the oldest container of 4, 5, 6, 7, and 8-barrel systems when 10% is removed once a year.

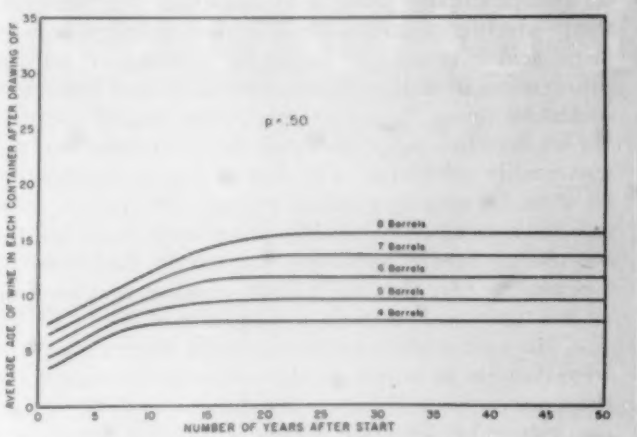

FIG. 3. Average age of the wine in the oldest container of 4, 5, 6, 7, and 8-barrel systems when 50% is removed once a year.

SUMMARY

A theory of fractional blending in a solera-type system has been developed and applied to three simple cases. It is clear that the terminal average age of the contents of the oldest container can be modified by changing the number of stages or the proportion of withdrawal or both. Additional modifications can be accomplished by changing the number of withdrawals per year, the original set-up of the system, and methods of replenishing the partially emptied containers. Some of these modifications are investigated in a longer paper to be published elsewhere.

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Notes and Letters

The Detection of Heterofermentation by Lactic Acid Bacteria

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It is often necessary to determine whether the spoilage of a certain sample of food is due to carbon dioxide-producing lactic acid bacteria. Furthermore, the production of carbon dioxide from carbohydrates by lactic acid bacteria has diagnostic significance for the differentiation of the homofermentative and heterofermentative types. It is necessary to use special methods for its detection since conventional procedures are not customarily successful. The detection of gas production by these bacteria is possible through the use of some one of a number of simple procedures, such as the inoculating needle technique, apparently first used by Leichmann *(3)*, the well known vaseline-paraffin seal, or the agar seal method of Gibson and Abdel-Malek *(2)*, but such qualitative tests are not always adequate. Identification as carbon dioxide of the gas produced, and its quantitative estimation sometimes may be of importance in classification studies.

The Eldredge tube *(1)*, suggested by the *Manual of Methods for the Pure Culture Study of Bacteria (4)* for the trapping and measuring of the amount of carbon dioxide produced by the heterofermentative types is not readily available in most laboratories in sufficient numbers for survey testing. Furthermore it is not a very sturdy piece of laboratory equipment. Recently in order to determine the fermentative behavior of a group of *Lactobacilli*, the device illustrated in Figure 1 and described here was successfully used to measure the amount of sugar converted to carbon dioxide by the heterofermenters.

Barium hydroxide solution was placed in a 8 x 1-inch test tube to a depth of about 1½ inches, and a 5 x ½-inch tube of well buffered glucose yeast extract broth, inoculated with the test organism, was quickly lowered into the larger tube which was promptly fitted with a rubber stopper. For fastidious strains it may be necessary to add 5% tomato juice to the medium. Heterofermentative types caused a copious precipitate of barium carbonate within 48 hours at 30-32° C. (86-90° F.). Recovery and determination of the amount of carbonate formed indicated that from 25 to 37% of the sugar on a weight basis was converted to carbon dioxide, the maximum conversion being effected by *Lact. fermenti*, one of the known heterofermenters used as a control. Most determinations were near a 25% value. Homofermentative types showed little or no more carbonate than uninoculated controls.

April 6, 1951.

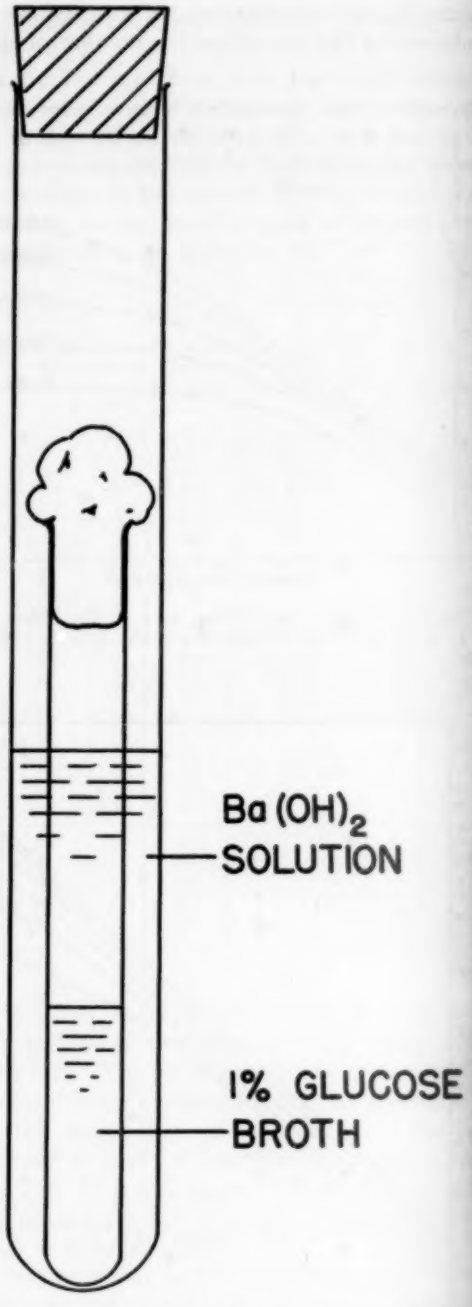

FIG. 1. Device for trapping carbon dioxide produced by heterofermentative lactic acid bacteria.

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